THE EFFECTS OF PAST AND CURRENT LAND DISTURBANCES ON SQUAW LAKE, MINNESOTA AND ITS WATERSHED

A THESIS
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA

By
William Albert Patterson, III

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

DEGREE GRANTED

June 1978

203414

ACKNOWLEDGEMENTS

This study could not have been completed without the assistance of many individuals. At the risk of oversite, I would like to acknowledge those who contributed their time and effort. The following assisted in the field sampling: Mark Boche, Mike Majeski, Norm Aaseng, Gary Twait, Maura Gage, Nancy Sather, George Jacobsen, Dick Brugam, Dan Reick, Jim Hermann, my brothers Jim and Roger, and my wife Joan.

Bob Boyle and Dave Bosanko provided valuable logistical support at the Lake Itasca Forestry and Biological Station. Without the interest and support of District Foresters Vern Miller and Gene Wroe, and Area Forest Supervisor John Rodewald the treatments at Squaw Lake would not have been carried out.

Bick Brugam and John Miller graciously allowed me to cite their unpublished data. Those who reviewed the thesis include Drs. H. L. Hansen, R. S. Farnham, E. Bakuzis, A. C. Mace, Jr., E.J. Cushing, and H. E. Wright, Jr. I am particularly grateful to Dr. Wright for his interest in the study and his many worthwhile suggestions. Dr. Cushing allowed me to use his laboratory facilities for pollen analysis, and, more importantly, provided guidance, encouragement, and enthusiasm.

The encouragement and friendly patience of my advisor, Dr. Hansen, was of particular value. I also appreciate the financial support provided by Dr. Hansen and Dr. Mace. In this regard, the support of Dr. F. H. Kaufert and Dr. R. A. Skok of the College of Forestry is gratefully acknowledged.

Finally, I would like to thank my wife, Joan for her continued support and encouragement throughout the past six years.

Plate 1. Squaw Lake, ca. 1913. (Courtesy of John Dobie, photo by Thorvold Schantz-Hansen)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

I. INTRODUCTION

This thesis attempts to identify the effects of natural and man-caused disturbances on terrestrial and aquatic ecosystems in Itasca State Park, Minnesota. A disturbance is considered to be an event that results in the disruption of ecosystem processes that would otherwise continue unchanged, either in a steady-state equilibrium or with a regular and predictable periodicity. A wide variety of natural and man-caused events meet this criterion. Examples of the former include windstorms, fire, unusual precipitation events, and earth upheavals such as volcanoes and earthquakes. In addition to disruptions of the physical environment, there are biological perturbations such as disease, grazing, and predation. Man-caused disturbances include land-clearing activities (burning and timber felling) and the addition of toxic or stimulating substances (e.g. herbicides, sewage effluent, radioactive materials). Persistent disruptions such as chronic air pollution or insect infestations are not considered disturbances as defined above.

Disturbance is an important factor governing the structure and function of ecosystems. This fact has been neither widely accepted nor long understood. Disturbance has traditionally been equated with destruction and considered undesirable and unnatural. This attitude is not unusual. Most organisms resist rapid change, and man is no exception. He has an inherent fear of the unknown. Disturbances disrupt the status quo and render the future uncertain. Furthermore the degree of uncertainty is often directly related to rate of change. Attempts to circumvent uncertainty pervade all aspects of social man's existence. In politics, those who wish to govern are often successful to the extent that they; 1) promise a return to former (and hence known) conditions, or 2) profess to be able to predict and control the rate and direction of change. The uncertainty of death is partially responsible for the belief in immortality, which is a characteristic of many religions. In conservation, early American efforts involved little more than the maintenance of conditions in their "natural" state (i.e. as they were when first discovered by European man).

In light of the above it is not surprising that stability is often considered the goal of plant succession. In referring to stabilization and climax Clements (1928) states that, "So universal and characteristic is stabilization that it might well be regarded as a synonym of succession." He views succession as an orderly and predictable process ultimately giving rise to self-perpetuating climax formations, the nature of which is governed by climate. Clements did not, however, ignore the importance of disturbance in plant community development. He recognized it as an important "initial cause" of succession and observed that persistent perturbations result in a disturbance climax or "disclimax." Disclimaxes were, however, viewed as modifications or replacements of true climaxes. They were considered to be unnatural and "nearly always the result of disturbance by man or domesticated animals" (Weaver and Clements 1938). Clements contributed much to our understanding of the role of disturbance in natural ecosystems. Unfortunately, post-Clementsian plant ecologists in North America have devoted much of their efforts to debate over his organismic concept of plant formations. This concept emphasizes the importance of autogenic succession, and the study of disturbance has been largely neglected. Even Whittaker (1951, 1957), one of Clements' more persistent critics, minimized the significance of disturbance when he analyzed the factors governing the species composition of the vegetation of the Great Smokey and Siskiyou Mountains (Whittaker 1956, 1960). He concentrated instead on defining gradients in the physical environment. Differences between stands were attributed to variations in the environment, rather than historical factors. Quite recently Henry and Swan (1974) were criticized when they concluded that disturbance (as opposed to autogenic succession) was the primary factor governing recent changes in species composition in a virgin forest in southern New Hampshire (J.M.A. Swan, conversation, 1976).

The natural role of disturbance in ecosystem dynamics has not been completely ignored. Tansley (1935), author of the ecosystem concept, recognized that both autogenic and allogenic factors may govern succession. He points out that "actual successions commonly show a mixture of these two classes of factors--the external and the internal" (Tansley 1929). Sukachev and Dylis (1968) classified successions of biogeocoenoses as either autogenous or exogenous successions. Among the later they recognized local catastrophic successions including anthropogenic, zoogenic, pyrogenic, and storm-damage successions, as well as successions caused by torrential floods, landslides, sudden inundations, and the like. Lavrenko (1959, cited in Sukachev and Dylis 1968) classified successions as being either secular, prolonged, rapid, or catastrophic. Catastrophic successions result when an original forest biogeocoenose undergoes a sudden violent change or complete destruction because of external factors. Whittaker (conversation 1976) acknowledged that disturbance may well be a more important factor in vegetation development than he originally perceived.

The above discussion is centered on terrestrial ecosystems. The character of aquatic ecosystems often depends on their surroundings, however. Although limnologists have traditionally treated lakes as isolated microcosms, Margalef (1968) warns that "lakes cannot be studied independently but must be associated with other peripheral ecosystems."

Two recent studies emphasize this point. Janssen (1967) studied the history of the vegetation of Stevens Pond near Itasca State Park. He observes that floristic changes over time have paralleled changes in the surrounding upland vegetation. Plants characteristic of nutrient-poor environments dominate the lowland when the upland is occupied by conifers. As deciduous trees invade the upland, the lowland vegetation becomes more mesotrophic. Janssen hypothesizes that deciduous trees, which cycle nutrients more rapidly, contribute relatively more nutrients to the lowland, the productivity of which is thus partially dependent upon the nature of the upland vegetation.

The influence of vegetation upon the quantity of hydraulic discharge has been illustrated by experiments at the Coweeta Hydrologic Laboratory, Franklin, North Carolina. Swank and Douglass (1974) report a 20 percent reduction in annual stream flow from a small watershed 15 years after the vegetation was converted from mature hardwoods to white pine (*Pinus strobus* L.) The authors cite increased interception and evapotransporation as important factors contributing to reductions.

The impact of land disturbance on aquatic ecosystems has long been recognized by foresters. Concern for the protection of water resources was an important factor leading to the establishment of the National Forest System in America (Douglass and Swank 1972). Early resistance to the use of prescribed burning as a management tool stemmed in part from fears that burning would lead to increased runoff, erosion, and flooding, according to Schiff (1960), who notes that apprehensions about prescribed burning were a natural consequence of the catastrophic effects of indiscriminate land clearing undertaken during the 19th Century in the eastern United States. The dramatic effects of vegetation destruction on water quality were recently illustrated for forests in central New Hampshire. Clear-cutting and herbicide treatments removed all vegetation from a small watershed at the Hubbard Brook Experimental Forest. Annual stream flow increased nearly 40 percent following the treatment, and water quality was seriously degraded as a result of increased nitrification in the shallow soils with low cation exchange capacity (Likens *et al*. 1970). Gerhart (1973) studied a small lake within the Hubbard Brook watershed and, extrapolating from the results of earlier studies, concluded that similar treatment of the lake's watershed would result in a nitrate loading rate 43 times the "dangerous" input rate. As a result of the studies at Hubbard Brook, vigorous debate has arisen over the ecological impacts of the silvicultural methods employed.

Recent concern over the impact of man's activities on the environment led to a number of experiments, the results of which have increased our understanding of man-caused disturbances. Few studies have, however, assessed the impacts of man-caused versus natural events. This is especially true where terrestrial-aquatic interactions are involved, and this fact strongly influenced the development of the problem I have undertaken.

II. OBJECTIVES

My overall objective is to evaluate the ecological significance of man-caused disturbances presently occurring in Itasca State Park relative to natural and man-caused disturbances that occurred in the past. The area I chose for detailed study is located in the northwestern portion of the park and includes Squaw Lake and a portion of its watershed. Specific objectives developed at the outset of the research include:

1. To assess the nature, extent, and ecological significance of past disturbances on Squaw Lake and its watershed.
2. To determine the impacts of selected silvicultural practices employed in the conversion of the watershed's vegetation from hardwood to pine on:
   a. the floristic composition and the quantity of overstory, understory, and herbaceous vegetation;
   b. the quantity and nutrient content of the forest floor;
   c. the quantity and quality of stream flow from the treatment area;
   d. the characteristics of lakes and ponds within or adjacent to the treatment area.
3. To evaluate the effect of vegetation type on the quantity and quality of throughfall in forest stands.

III. SETTING

Itasca State Park provides a unique opportunity for a problem of this nature, because of its geographic location and its land-use history.

A. Regional Physiography

Located in northwestern Minnesota (Lat. 47° 11' N. Long. 95° 13' W.), Itasca State Park is positioned on the Itasca Moraine. Its landscape is dominated by hills interspersed with numerous lakes, the largest of which is Lake Itasca--the source of the Mississippi River. The Minnesota Legislature established the park in 1891 to protect the headwaters of the Mississippi. Itasca State Park lies in close proximity to the prairie-forest border, and its flora contains elements of the prairie, boreal, and deciduous vegetation formations. McAndrews (1966) identified climatic fluctuation as the factor governing the relative importance of elements from these diverse formations during the post-glacial period (approximately the last 10,000 years). The present climate is strongly continental with cold, dry winters and warm summers marked by frequent, intense precipitation events. Annual precipitation averages 25.2 in (64.0 cm) with less than 20 percent occurring in the form of snow.

The park's natural history is well documented as a result of teaching and research activities associated with the University of Minnesota's Forestry and Biological Station. Since 1909 foresters and biologists have utilized this facility as a base of operations for studying the fauna and flora of the area. General reviews of the climate, vegetation, geology, and soils are found in McAndrews (1966), Wright and Ruhe (1965), Kurmis (1969), Ness (1971), and Hansen et al. (1974). Numerous more specific studies have been conducted, and information from these studies will be cited as deemed appropriate.

B. Historical

Archaeological excavations have recently shown that American Indians frequented the Itasca region as early as 9,000 years ago (Shay 1971). European man first settled the area in the 1880's, although frequent earlier explorations were conducted in conjunction with attempts to locate the headwaters of the Mississippi. Brower (1893, 1904) provides a detailed account of the earliest explorations and of the controversies surrounding the park's establishment. Land-clearing activities of early timber interests did not reach Lake Itasca until after the park was established, and, as a result, the park has large tracts of virgin pine, which have become a major tourist attraction. Recent studies document the fact that these pine stands arose as a direct result of wildfires which periodically burned the area prior to the arrival of European man (Spurr 1954, Frissell 1971). Fires were started either by Indians or naturally by lightning, and studies by Heinselman (1973) in northeastern Minnesota show that fire was an important, naturally occurring event in the pre-European forests.

Logging did occur within the present park's boundaries, especially in its western portion, where land was not acquired by the state until after the timber had been removed by private lumber companies. General accounts of early logging activiites are available in Brower (1904), Dobie (1959), and Vandersluis (1974). A comprehensive review of the extent of early logging in the park has recently been completed by Aaseng (1976).

C. Present Condition

Approximately 35 percent of the upland area in the park is presently occupied by pine species (after data presented in Hansen *et al*. [1974]). Red pine (*Pinus resinosa* Ait.) occurs on more than 57 percent of the park's 8,783 acres of pine. White pine and jack pine (*Pinus banksiana* Lamb.) occupy 14.6 and 17.8 percent of the total pine acreage. Many areas contain mixtures of either red and white or red and jack pine, and the above figures are for the dominant species. Of the nearly 9,000 acres of pine forest, less than 5 percent are considered to be immature (less than 100 years old). Aspen (principally *Populus tremuloides* Michx.) and paper birch (*Betula papyrifera* Marsh.) are the dominant tree species in 61 percent of the upland vegetation. Nearly 60 percent of the aspen-birch forests occur in the logged-over western third of the park.

Recent studies by Kurmis (1969) and Ness (1971), combined with results of Frissell's study, indicate that the present lack of pine regeneration results from protectionist management policies. Since 1920, no fires have been allowed to burn within the park's boundary. Hunting and trapping restrictions plus the elimination of natural predators have allowed animal populations (chiefly of white-tailed deer and porcupine) to exceed habitat carrying-capacities. Disturbance in the form of logging has been limited to the salvage of diseased or wind-damaged trees and has been conducted only intermittently. On those areas logged in the early 20th Century, the removal of seed trees, the burning of slash, and the failure to establish new stands by planting or seeding resulted in an almost total lack of pine regeneration in the park.

The desirability of perpetuating pine for recreational and ecological reasons has been documented (Hansen and Duncan 1954, Klukas and Duncan 1967, Hansen et al. 1974). As a result of these studies, the Minnesota Department of Natural Resources has recently adopted a management policy designed to perpetuate the virgin pine stands of the park, and, at the same time, reestablish pine where it occurred prior to early logging. Disturbance is being encouraged after nearly fifty years of suppression. Five small areas (each less than 12 ha in size) were logged beginning in 1967. The objective of these early trials was to develop techniques for reestablishing pine on areas now occupied by aspen-birch forest. In addition to logging, a variety of silvicultural techniques including prescribed burning, herbicide spraying, mechanical site preparation, artificial seeding, and hand planting was tested to determine the most effective means of stand conversion.

D. Squaw Lake

On the basis of information gained from earlier trials, a larger "operational" treatment area was selected in 1972. The site encompasses approximately 113 ha and is west of Squaw Lake and northeast of Myrtle Lake in the extreme northwest corner of the park. All of the NW¼, Sec. 6, T.143N.-R.36W. is included, plus portions of adjacent ¼ sections to the east, south, and west.

Frissell (1971) reconstructed the park's presettlement vegetation using records from the General Land Office survey. His map shows that prior to 1900 Squaw Lake was surrounded by pine forests. Between 1905 and 1917 virtually all the pine at Squaw Lake was removed by private lumber companies (Dobie 1959). The state obtained the land for park purposes shortly after it was logged over, and little development has occurred along the lakeshore since that time. Aspen and birch succeeded pine on much of the watershed, and subsequent fire suppression has allowed the development of mature hardwood forests. The area was chosen for site conversion because pine grew there originally, because it contained saleable timber, and because its location made burning feasible.

Treatments proposed in 1972 included both logging and burning, disturbances that were historically important to Squaw Lake and its watershed. The potential for detailed reconstructions of past disturbances, while carefully monitoring the proposed disturbances, strongly influenced my decision to study the area.

IV. METHODS

The choice of experimental design for analyzing the effects of disturbance depends both upon the specific objectives of the research and the nature of the disturbance in question. Typically, short-term changes in ecosystem processes are monitored and results are compared with baseline data gathered under controlled, undisturbed situations. Pre-treatment and post-treatment data may be gathered from the same site if sufficient time is allocated for adequate calibration. Alternatively, data may be gathered from two separate sites, one of which serves as control and the other treatment. Each technique has advantages and disadvantages. In the case of the former, definition of an adequate calibration time is somewhat arbitrary. Frequently the required calibration times are too long and preclude the technique as a sole source of information. Also, the spatial and temporal unpredictability of natural disturbances precludes the establishment of pre-disturbance conditions. The use of analogue areas, on the other hand, allows simultaneous calibration and collection of post-disturbance data. Wright (1974) employed this method effectively in analyzing the effects of wildfire on lakes in northeastern Minnesota. Care must be taken when using analogues, however, to insure that treatment and control areas are similar with regards to the processes studied. In some instances the establishment of similarity may, in itself, require a calibration period.

The two techniques can perhaps best be utilized in combination as has been done at Hubbard Brook and Coweeta. The constraints of time and work in the Squaw Lake study forced a somewhat different approach, however. Only one year each could be allotted for collection of pre-treatment and post-treatment data. Such a short time is inadequate both for calibration and for the monitoring of disturbance effects. Instead I have chosen to combine neoecological and paleoecological techniques. By so doing, I emphasize the temporal rather than spatial aspects of disturbance ecology.

A. Paleoecological Studies

The objectives of these studies are two-fold; 1) to reconstruct the nature and extent of disturbances, and 2) to attempt to ascertain something of the nature of the effects of past terrestrial disturbances on Squaw Lake. The accomplishment of the first objective was aided by the efforts of researchers who worked in advance of, or in conjunction with, this study.

1. Fire history. The fire history of Itasca State Park was investigated first by Spurr (1954) and later by Frissell (1971) who constructed maps showing the extent of major fires occurring since 1659. Because he relied upon fire scars and stand-origin data, Frissell's maps are rather imprecise in areas that were logged-over. For example, he used only one stump cross-section for reconstructing the occurrence of fire in the area surrounding Squaw Lake. His data are valuable, however, in that they identify those years in which fires burned extensively.

I have used Frissell's techniques to obtain additional data for the Squaw Lake watershed. The early logging at Squaw Lake left pine stumps, some of which are well enough preserved to allow sectioning. A reconnaisance of the west shore of the lake in 1974 located six stumps from which sections were cut. On all but two of the stumps, the tree's pith was preserved. Well-preserved stumps, with readily identifiable fire scars, were found only on the steep slopes near the lake, however. Where understory growth was more prolific, stumps were less well preserved. To obtain information for these areas, partial sections were spot checked.

Fire history was also obtained from standing trees or those recently cut. The unlogged S½, SW¼, Sec. 6 contains pine that date from about 1820. Increment cores from several of these trees were obtained, and scars appearing at the base of the stems were dated by noting narrow bands in the increment cores. The same technique was used to date fire scars on old growth pine scattered about the Squaw Lake treatment area. The logging of approximately 8 ha of jack pine on the treatment area provided an opportunity for the careful examination of freshly cut stumps. Most of these trees apparently regenerated following fires in the early 1890's. Over 1700 stumps were checked, and scars on several stumps were dated in an effort to identify fire years.

In addition to data collected in the field, written records were reviewed for information on fires occurring on the area since 1895. Especially useful were the annual reports of Minnesota's Chief Fire Warden (1895-1904) and Forestry Commissioner (1905-1910). The State of Minnesota has maintained a District Forestry Headquarters in the park since 1924, and the few fires that have occurred in the park since then are well documented.

2. Logging history. General accounts of logging in the Itasca area have been available for some time, but until recently a detailed review of logging activities was unavailable. The initial investigations of logging at Squaw Lake were expanded to include the entire park by Aaseng (1976) who interviewed area residents; examined state, county, and local historical archives and government records; and conducted field investigations. Much of what is known of the logging of the Squaw Lake watershed comes from Aaseng's efforts.

3. Sediment studies. Information gained from the fire and logging history studies provides an adequate reconstruction of the recent occurrence of these disturbances. Sediment cores were obtained in order to determine the effects of disturbance on the upland vegetation and aquatic ecosystems. Pollen, charcoal, and chemical analyses were performed on sediment cores taken on 17 December 1973. Cores approximately .75 m long were recovered at depths of 24 m (Squaw Lake) and 6 m (Myrtle Lake).

a. Coring technique and sediment sampling. A modified Livingstone sampler (Cushing and Wright 1965) was used to obtain unfrozen sediment cores. A 15-cm-diameter core of the 0-26 cm interval was obtained from Myrtle Lake, whereas 5-cm-diameter cores of the 25-70 and 0-68 cm intervals were obtained from Myrtle and Squaw Lake, respectively. Cores were kept in an upright position during transport from the field to the Forestry and Biological Station where they were sampled. Care was taken to avoid mixing the sediments. Cores were extruded from the top of the plastic coring tubes within 12 hours of their being removed from the lake and sectioned as follows: Squaw Lake 0-50 cm:.5 cm intervals; Myrtle Lake 0-26.1 cm:.3 cm intervals, 25.6-43.0 cm:.6 cm intervals, 43.0-57.4 cm:1.2 cm intervals. Sediment samples were placed in sealed, plastic containers and stored at $4^{o}C$ in the absence of light.

In addition to the unfrozen cores, five frozen cores were obtained using a method modified from that of Shapiro (1958). In this technique a rectangularly shaped, long, metal coring device is filled with a mixture of butanol and dry ice. The core tube is then sunk .75-1 m into the sediments. After about 30 minutes, the core tube is recovered with a .5-2 cm crust of sediment frozen to the outside. If care is taken in lowering the sampler into the sediments, sediment structure is preserved in the frozen crust and can be examined in detail following retrieval. One core was obtained from Squaw Lake adjacent to the site of the unfrozen core. On February 9, 1976, additional frozen cores were obtained from Squaw Lake along a transect at the southwest end of the lake (see Figure 1). After removal from the coring device, frozen sediment slabs were wrapped in aluminum foil and plastic to prevent sublimation, and they were stored in a freezer.

b. Physical and chemical analyses. Moisture, organic matter, ash content, and bulk density were determined by heating 2 or 3 cc of wet sediment, first to $80^{o}C$ (for 24 hours) and then to $500^{o}C$

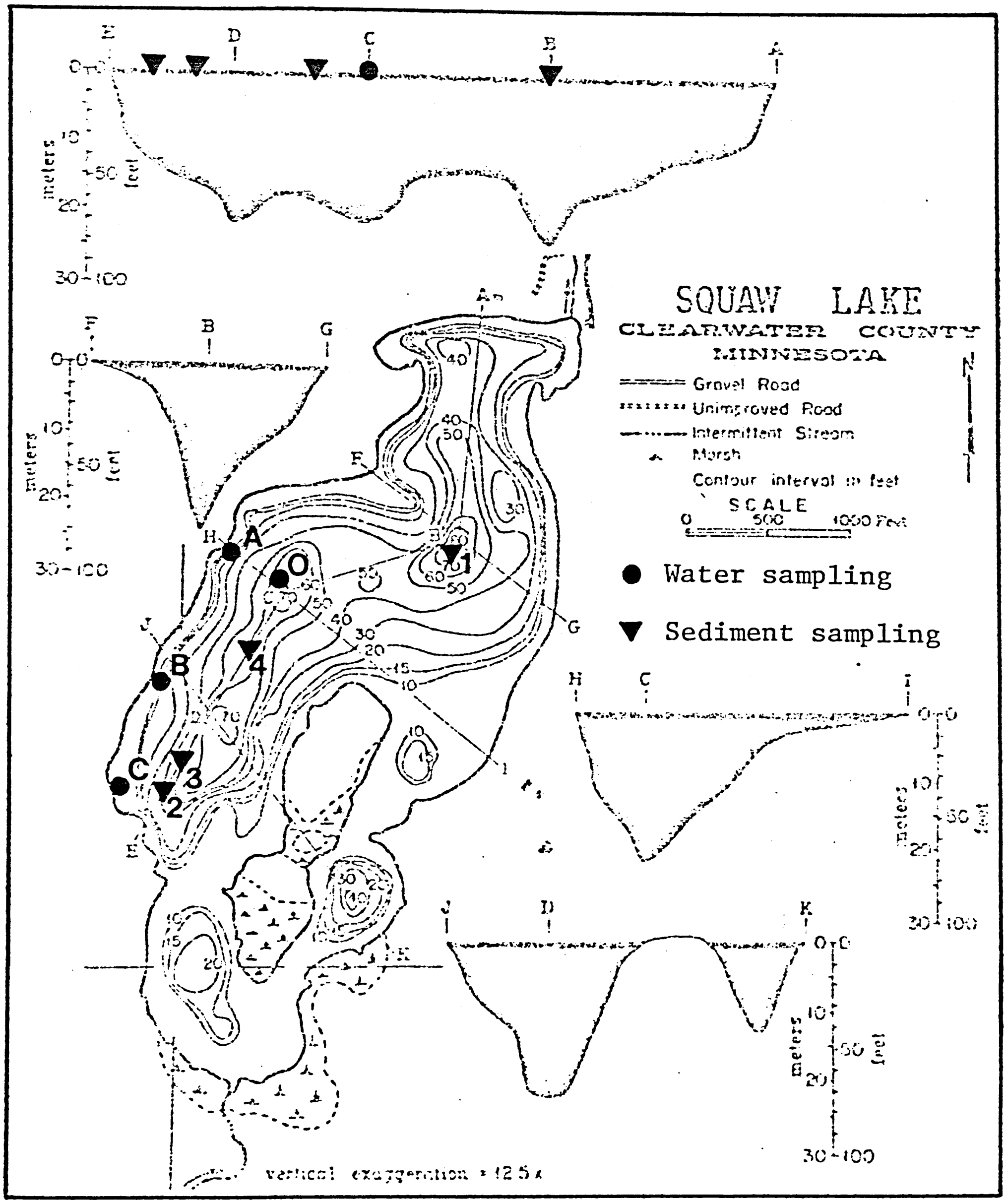


Figure 1. Morphometric map of Squaw Lake showing sediment and water sampling sites.

(for 4 hours). The desired values were obtained using the following formulae:

(4.1) water as percent wet weight: $\dfrac{100\ (W_2-W_{80})}{W_2-W_1}$

(4.2) organic matter as percent dry weight: $\dfrac{100\ (W_{500}-W_{80})}{W_{80}-W_1}$

(4.3) ash as percent dry weight: $\dfrac{100\ (W_{80}-W_1)\ -(W_{80}-\ W_{500})}{W_{80}-W_1}$

(4.4) bulk density as gm/cc: $\dfrac{(W_{80}-W_1)}{V}$

where; W_1 = crucible weight to the nearest .1 mg,

W_2 = weight of crucible plus wet sediment,

W_{80} = weight of crucible plus sediment after drying at 80°C,

W_{500} = weight of crucible plus sediment after ignition at 500°C,

V = volume of wet sediment.

The ignited samples were prepared for chemical analysis as follows. A solution of 0.5 percent Li_2CO_3 in 15 percent HCl was added to each sediment sample. A 30-fold dilution was prepared gravimetrically, and samples were allowed to soak for 36 hours at a temperature of 4°C. Crucibles were covered to prevent evaporation. After being soaked, the saturated sediments (which had initially been hardened by ignition) were crushed to a fine consistency with a glass rod. The resulting suspensions were centrifuged at 2000 rpm, and, when the solutions cleared, the supernatent was removed and diluted 5-fold. The resulting 150-fold dilutions were analyzed for P, K, Ca, Al, Na, Fe, Mg, An, Cn, Mo, Mn, and B using a 1.5 m Jarrell-Ash Spark Emission Spectrometer. Samples were found to contain very high concentrations of Fe. Because Fe interferes positively with P on the emission spectrograph, concentrations of these two elements were determined independently--Fe by atomic absorption spectroscopy and P on a Technicon Auto Analyzer II employing the phosphomolybdate method with ascorbic acid reduction (EPA 1971).

For approximately 10 percent of the Squaw Lake samples, calcium carbonate content was determined by loss on ignition. The computation is as follows:

$$\text{(4.5)} \quad CaCO_3 \text{ as percent dry weight} = 227 \frac{(W_{950}-W_{500})}{(W_{80}-W_1)}$$

Where: W_{950} = weight of crucible plus sediment after ignition at $950^{o}C$ for 4 hours.

Galle and Runnells (1960) propose this method for carbonate rocks and Dean (1974) discusses its applicability to sediments.

c. Fossil analyses. Subsampling of the unfrozen Squaw Lake sediments was accomplished in February, 1974. After thorough mixing, 1 cc of each sample was placed in a glass vial and preserved with a glycerin-formalin solution. Preparation of the sediment for pollen analysis followed the procedure of Faegri and Iversen (1964) and included treatment with 10 percent KOH, 10 percent HCl, 48 percent HF, and acetolysis. Sieving was unnecessary, but the high content of organic acid and silt-clay in the sediments necessitated frequent (10-12) washings after deflocculation with KOH. Prior to preparation a known quantity of reference pollen (Eucalyptus in glycerin at 77,060$\pm$2.84 S.E. grains/ml) was added to the sample so that pollen and charcoal counts could be expressed as concentrations (Benninghoff 1962). Following preparation, residues were mounted in silicone oil. Myrtle Lake sediments were prepared in a similar fashion, although subsampling was not done until the sediments were prepared, and fewer washings (4-6) were required following deflocculation.

1) Pollen analysis. Thin slides (20-30μ) were prepared, and all pollen and spores were counted on approximately 25 equally spaced traverses. Routine counting was done with a 10X eyepiece and a 40X apochromat objective (n.a.=.95). Difficult grains were viewed with an oil-immersion objective (90X, n.a.=1.30). Pine pollen was identified as being Diploxylon (*Pinus banksiana* or *P. resinosa*), Haploxylon (*P. strobus*), or undifferentiated. Initially, separate thick slides were prepared for the determination of the ratios of the three types. Thick slides allow the grains to be turned so that the presence or absence of distal verrucae can be determined (McAndrews *et al.* 1973). With some experience I found it possible to determine satisfactorily ratios from the thin slides, and the preparation of thick slides was abandoned. Pollen diagrams and summaries were prepared with use of a modified FORTRAN program (POLDATA) written by E.J. Cushing.

2) Characoal analysis. Charocoal determinations were made from the pollen slides. Swain (1974) found that using pollen preparations was more efficient and no less satisfactory than preparing sediments separately by nitric acid digestion. I determined charcoal concentrations according to the method first described by Waddington (1969) and later modified by Swain (1974). Briefly, the area of individual charcoal fragments is measured with an eyepiece graticule. Fragments are tabulated by size classes, and the sum of the area in the individual size classes is expressed per unit of sediment (e.g. μ^2/cc or μ^2/gm oven dry weight). A graticule 18.6 μ square was used, and sample-to-sample standardization was accomplished by counting Eucalyptus grains along with charcoal fragments. Fragments were tallied in 11 size classes; 0.25-.5, .5-1.0, 1.0-2.0, 2.0-4.0, 4.0-8.0, 8.0-13.0, 13.0-18.0, 18.0-23.0, 23.0-28.0, 28.0-33.0, and 33.0-38.0 squares. Particles smaller than .25 square were ignored, while those larger than 38.0 squares were tabulated individually. Swain (1974) demonstrated that the above technique yields reproducible results level-by-level. A review of the use of charcoal as a fossil indicator of fire and an analysis of the methods of expressing charcoal were incorporated into the study but will be reported elsewhere.

d. Sediment dating. Two techniques were used to gain a stratigraphic time control. The relative abundance of pollen from agricultural weeds has been used to identify a settlement horizon in the Itasca Region (McAndrews 1966, Janssen 1967). The lower boundary of this horizon was determined to be 1890 by Foster (1976) who analyzed annually laminated sediments from Lower LaSalle Lake, located approximately 6 miles northeast of Squaw Lake. Accepting this date for Squaw Lake allows the calculation of a sediment accumulation rate for the uppermost sediments. By extrapolating to older sediments, the sediment accumulation rate can be used to tentatively date events occurring prior to 1890. More recent events are dated by interpolation.

In order to date the older sediments from Squaw Lake, a carbon-14 (C-14) date was obtained. One half of the 50-60 cm interval from the unfrozen core was sent to Isotopes, Inc. for analysis. The sample was pretreated for the removal of carbonates, and a Libby half-life of 5568 years was used to calculate the age. From the date obtained by C-14 analysis, dates for the 0-50 cm interval were determined by interpolation. The two dating techniques provide independent methods for dating events observed in the sediment profile.

B. Neoecological Studies

The field investigations conducted during the course of this study were designed to characterize the effects of logging and prescribed burning on the terrestrial and aquatic ecosystems of the Squaw Lake area. At the outset it was felt that not more than three years could reasonably be allotted to field sampling. This time constraint influenced the experimental design. An additional important consideration was the fact that prediction of the nature and extent of logging on the area was impossible. The actual cutting, which took place in January, February, and March, 1974, was undertaken by a commercial logger and adherence to the logging contract was not strictly enforced. As a result, the degree of tree removal was influenced more by market conditions than prior specifications, and some of the timber planned for clearcutting was only partially cut or not cut at all.

Burning of the area was originally planned for fall, 1974, but only a small five-acre tract was burned at that time. The rest of the area was burned the following spring. The unpredictability of burning conditions was realized in advance, and greater emphasis was placed upon the characterization of logging effects.

The summer of 1972 was devoted to a general reconnaissance of the proposed treatment area. Throughfall studies and aquatic sampling were initiated in September, 1972 and were continued through the fall of 1974. Pre-treatment vegetation data were collected during the summer of 1973, and post-logging data were collected in 1974. A limited amount of post-fire data was collected in 1975.

1. Terrestrial vegetation. The fire line shown on Plate 2 was constructed in June, 1973. A map of the enclosed area was subdivided using a grid with .4 ha squares. Nineteen of these squares were selected randomly, and their centers were located with respect to mature red pine near the intersection of Sections 5 and 6 (T.143N.-R.36W.) and 30 and 31 (T.144N.-R.36W.). Bearings and disturbances from this tree were used to locate points in the treatment

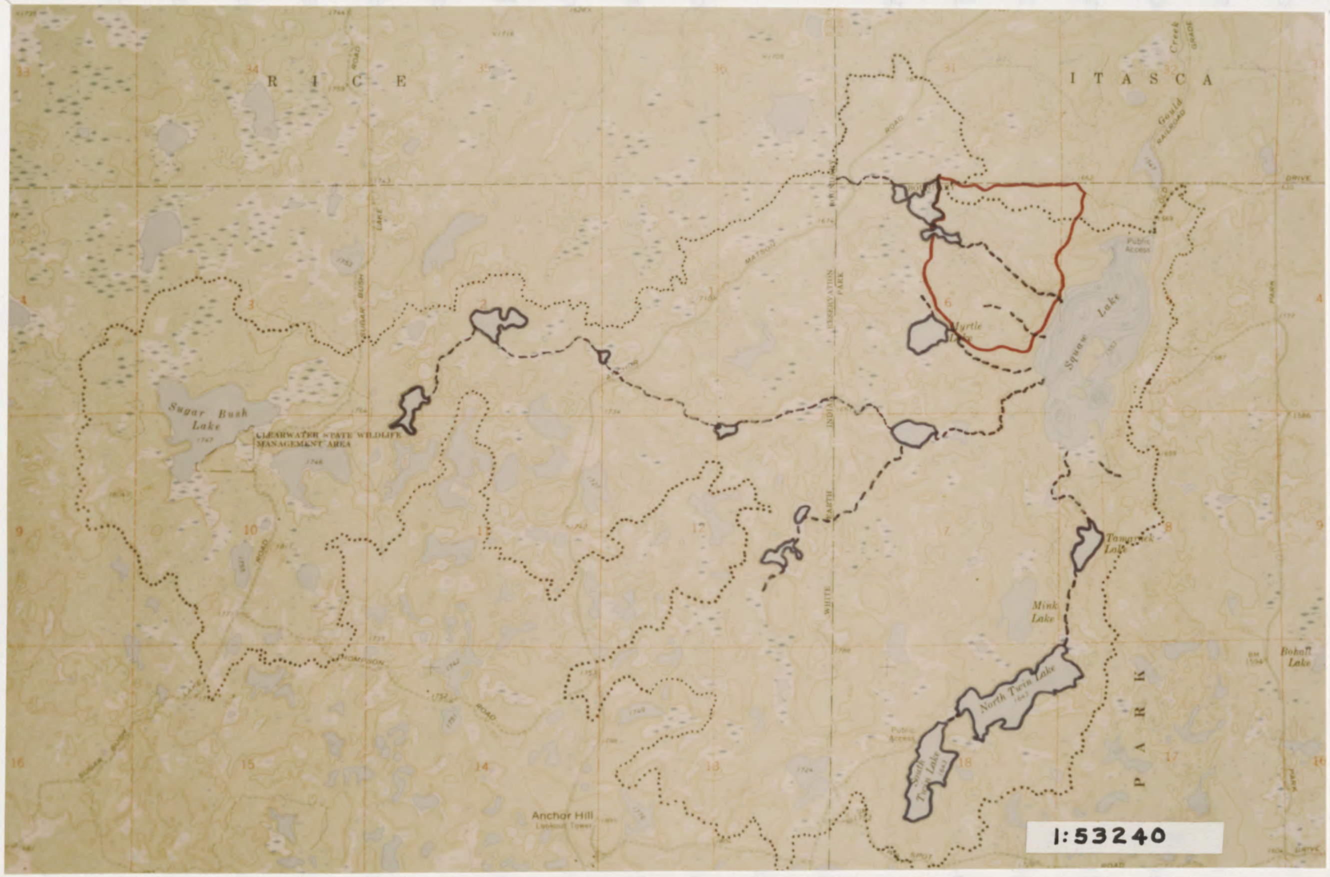


Plate 2. Topographic map of the Squaw Lake area. The red solid line is the fire break. The black dotted line is the Squaw Lake watershed boundary.

area. These points served as centers for 0.1 acre (.04 ha) plots, descriptions of which provide the basis for the vegetation analysis. I chose to intensively sample a relatively large number of small plots because the sampling of a few larger stands may have proven unproductive due to the unpredictable nature of the treatments. By distributing the plots randomly about the area I hoped that at least some of them would be in areas eventually logged and/or burned. Small plots were further necessitated by the hilly nature of the topography that results in sharp vegetation transitions.

When the points were located in the field, a subjective evaluation of the homogeneity of the overstory was made. Plots with obvious discontinuities were rejected. Because of past disturbance history and many small depressions, the establishment of plots with homogeneous overstory, understory, and herbaceous vegetation was impossible, and intensive subsampling of herbs and shrubs was necessary. Fifteen circular subplots with areas of 1 m^2 were selected within each large plot by the random toss of a small object. Plots were located permanently, but subplots were reestablished each year. Difficulty encountered in relocating plot centers after disturbance and the destructive nature of herbaceous biomass sampling necessitated the location of temporary subplots.

In 1973 the overstory vegetation on the nineteen plots was either jack pine (approximately 20 percent of the area) or aspen and/or birch. All plots are designated by an alphabetic character. Where treatment governed stand age, a numerical character (3, 4, or 5) is also used in the plot designation to indicate the year of sampling (e.g. 1973, 1974, or 1975). In addition to providing pre-treatment and post-treatment data, these plots yield information on the nature of the forest 50 to 60 years following the logging and burning that occurred in the early 20th Century. More-detailed successional data were obtained from the analysis of five additional sites.

Two plots, one in mature jack pine (plot J) and one in mature aspen (plot A), were selected within the treatment area. The stands were chosen because their high stocking levels suggested that they would most likely be cut. Three plots were located outside of the treatment area. One, on the shore of Squaw Lake, is a stand of pole-sized second-growth red pine (plot R3). A young red pine plantation (R4) is north of the treatment area. The third plot (Z4) is east of Squaw Lake and contained sapling-size aspen. The sapling pine and aspen stands were established at about the same time following logging in the late 1960's.

The study of these five plots provides a chronology of post-disturbance forest development that spans 50-60 years. Immediate post-disturbance conditions were studied on plots A and J. Young stands were sampled on plots R4 and Z4, and older, post-disturbance communities were analyzed at plots J, A, and R3. The selection of plots in aspen (A and Z) and pine (R3, R4, and J) provides a contrast between deciduous and coniferous vegetation types. In addition to recording vegetation parameters, throughfall was sampled on the five plots, and the forest floor was sampled more intesively for seasonal variability.

a. Plot description. A general description of the sampling sites was made when the plots were located. Descriptions included survey date, plot location and topography, indications of disturbance, and an estimate of Bitterlich basal area. Each plot center was photographed during the spring and fall of 1974 and 1975.

b. Overstory. All living and dead trees and stumps occurring on the 0.1 acre plots were tallied. Trees are defined as those with aerial stems larger than 1 in (2.5 cm) diameter at breast height (dbh) (4.5 ft =1.5 m). Aerial stems broken off or cut lower than breast height were considered to be stumps. Parameters recorded for trees include genus and species, condition (living, dead, diseased), crown class (dominant, codominant, intermediate, or suppressed), evidence of fire scars, and dbh (in inches). Height was determined with a Haga altimeter for seven of the living codominant individuals of the predominant species. Cores were taken from each of these seven trees with a Swedish increment borer. Generally cores were taken about 12 in (30.5 cm) above the ground for pine and at dbh for aspen and birch. Variations in coring height were taken into account when ages were tallied. For stumps, evidence of cutting and fire scars was noted, and diameter (approximately 12 in above the ground) was recorded when possible. Preservation of stumps was subjectively determined to be good, fair, or poor depending upon whether diameters could be measured, estimated, or not determined. Complete overstory data for plots occurring within the treatment area were recorded during the initial survey. Subsequent surveys only recorded species, condition, and dbh of the remaining stems.

c. Understory. Woody stems less than 3.2 cm in diameter at 20 cm above the ground were sampled on each .1-acre plot using 15, 1-m^2 subplots. For each subplot the genus and species of all stems were recorded. Average height for each species on each subplot was estimated. Stems were tallied with respect to condition (living or dead) and diameter (at about 0.2 m), the latter in 2-mm intervals between 0 and 3.2 cm. Seedlings less than 0.2 m total height were tallied in the lowest diameter class. Because they had a greater number of these seedlings, most 1974 and 1975 plots were tallied with 0-1 mm and 1-2 mm size classes as opposed to the 0-2 mm class used in 1973. Similarly, only stems up to 3.0 cm were recorded in 1974 and 1975, for fewer large stems were present following disturbance. Basal-area calculations considered all stems to be at least 0.2 m tall. The presence of stems less than 0.2 m had little effect on plot basal-area totals, however, and it is felt that their inclusion in basal-area calculations is justified.

d. Herbs. Fifteen 1-m^2 circular subplots were located on each plot for sampling herbaceous vegetation. Only in 1975 were herbs and shrubs sampled on the same subplots. The presence of all non-woody vascular plants was recorded for each subplot. All species represented by stems of the current years growth and rooted in the subplots were tallied. Where genus and/or species were indetermin-able (as in nonflowering graminoids), presence was recorded as unknown grass, unknown sedge, etc. In this way species diversity indices could be determined in the absence of complete specific identifications.

Biomass estimates of herbaceous cover were obtained by clipping all vegetation rooted on .1-m^2 rectangular plots (20 cm x 50 cm) located within the 1-m^2 subplots. Clippings were dried at 80^{o}C for at least 24 hours and weighed. Plant materials were prepared for chemical analysis by grinding to pass a 20-mesh stainless-steel screen. Samples were then ashed in fused silica crucibles for four hours at 500^{o}C. The ash was taken up in an acidified Li_2CO_3 solution (0.5 percent Li in 15 percent HCl) and analyzed on the emission spectrograph for the elements mentioned earlier. A 10:1 dilution ratio was maintained. Tissue samples were composites of all species on the subplots, and no attempt was made to analyze tissues of individual species.

2. Soils. Physical and chemical characterisitics were determined for the organic and mineral soil horizons. Emphasis was placed upon sampling the forest floor, for it was felt that the treatments would most directly affect the soil surface. The objectives of mineral soil sampling were to characterize the soils of the area and gain an estimate of variability.

a. Forest floor. Fifteen randomly selected 5.4-cm diameter cores of the forest floor were taken from each .1-acre plot. An impact bulk density sampler was used to extract the cores. All plots were sampled in mid-summer, and additional samples were taken in the spring and fall from intensive sampling plots. Depth of the forest floor was recorded at each sampling site, and moisture content, dry weight, and bulk density were determined. Chemical analyses were performed on the samples with the emission spectrograph. Preparation was as for the herbaceous material, except that soils were passed through a 2-mm sieve (to remove pebbles) prior to grinding.

b. Mineral soil. Ten soil pits were excavated, one each at plots A,D,E,G,J,L,L,M,R3,R4, and Z. Sampling was done during September and October 1973 and in September 1974 (plots R4 and Z). At each plot a site was selected that appeared to be typical of the surrounding terrain. A pit 3-4 ft (1-1.25 m) deep was dug and the soil profile described. An attempt was made to sample all of the profile including the C horizon, but this was not always possible. Composite samples were taken from the major soil horizons and used for laboratory analyses.

1) Physical properties. Bulk density was determined by excavation (Blake 1965), for the presence of large stones precluded the use of an impact corer. Soil samples were dried at 80°C for at least 24 hours and moisture content determined. Samples were then crushed to pass a 2-mm sieve, and the fraction larger than 2 mm was weighed to gain an estimate of the ratio of coarse to fine material. All subsequent analyses were performed on the <2 mm fraction. Particle-size distributions were determined with a modified Bouyoucos hydrometer method (Grigal 1973). Organic-matter content was determined by weight loss on ignition (Wilde *et al*. 1972).

2) Chemical properties. Soil reaction was determined for 1:1 (1:5 for A1 horizon) soil/water mixtures using a Beckman Zeromatic pH Meter. A Beckman SoluBridge was used to determine the electrical conductivity of 1:2.5 soil/water mixtures (Wilde et al. 1972). The following chemical determinations were made at the University of Minnesota's Research Analytical Laboratory under the direction of R.C. Munter: Kjeldahl N (Blake 1965); extractable P (Bray and Kurtz 1945); total P (Tandon et al. 1968); total exhangeable Ca, Mg, Na, and K (USDA 1972); exchangeable hydrogen (Chapman and Pratt 1961); and cation exchange capacity (USDA 1972).

3. Throughfall. Initially, estimation of the quantity and quality of throughfall in different vegetation types was to have been an important objective of this study. This effort was frustrated, however, by the persistent and uncontrollable destruction of the samplers by animals (chiefly black bears). Some useful information was obtained, nonetheless, and sampling and results will be briefly discussed.

Fifteen collectors were placed in each of the intensive-sampling plots. A sampler consisted of a 2-liter plastic bottle equipped with a plastic funnel (15-cm-diameter mouth). Early attempts to keep litter from collecting in the funnels proved unsuccessful, and they were later equipped with plastic rims 8 cm tall so that the litter that fell into the funnel openings was retained and did not blow out. A fiberglass plug was fitted to the neck of the funnel. As a result of this design, throughfall samples included nutrients that were washed from the litter that collected in the funnels. The samplers were placed in holes so that the funnel openings were 15-30 cm above the ground. Five collectors were placed in open areas so that gross precipitation could be sampled. Rainfall intensity and duration were monitored with a recording rain gauge. The location of all rainfall/throughfall monitoring sites is shown on Figure 2.

Field sampling consisted of recording the volume of throughfall contained in each sampler, emptying litter from the funnel, and replacing the fiberglass plugs. Plugs were washed with 10 percent HCl prior to installation. Throughfall samples (400-500 ml) were placed in clean plastic bottles for laboratory analysis and were frozen until analyses were performed.

Routine chemical analyses included $PO_4^{=}$ (ascorbic acid technique using a Technicon Autoanalyzer) total P ($H_2SO_4 + K_2S_2O_8$ oxidation followed by analysis as with $PO_4^{=}$, and NO_3^{-} by the brucine method (American Public Health Assoc. 1971).

Sampling was accomplished at irregular intervals depending upon rainfall patterns. The sample bottles held approximately 11 cm of precipitation, but the occurrence of several unusually intense precipitation events during the 1973 sampling season (e.g. 15+ cm in a 72-hour period in early September) resulted in the overflow of some of the samplers. The combination of sampler destruction (as many as 2/3 of the samplers were disturbed in a two to three-week sampling period) and occasional sampler overflow precluded the calculation of annual budgets. Comparative analyses of autumn throughfall patterns were possible, however. This is fortuitous for

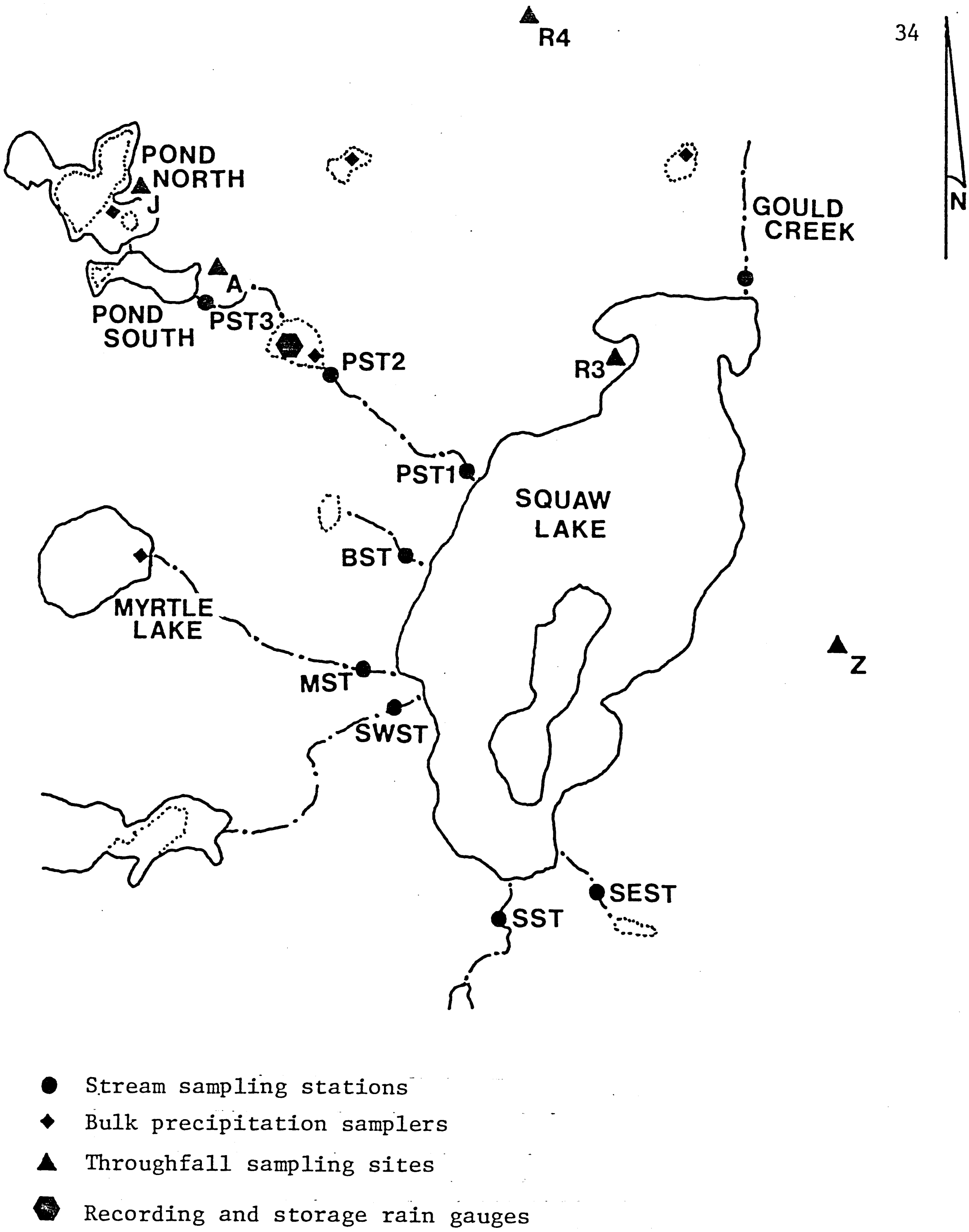


Figure 2. Map showing hydrologic sampling stations.

concentrations of P were generally highest during leaf senescence and fall.

4. Hydrologic systems. Squaw Lake, some of its tributary ponds and streams, and the local groundwater were sampled intensively between 1972 and June 1975. The studies yielded data upon which interpretations of the results of the historical investigations could be made. They also documented the short-term effects of the logging operation on Squaw Lake.

a. Lakes. Squaw Lake, Myrtle Lake, and two beaver ponds, hereafter referred to as ponds North and South (Figure 2), were sampled at intervals ranging from 1-3 weeks (summer) to 6-8 weeks (winter). Sampling schedules were adjusted to allow intensive sampling of late-summer algal blooms. The frequency of sampling during the winter months was governed in part by weather conditions, which occasionally made travel to the lakes difficult.

Squaw Lake was of greatest interest and was therefore sampled most intensively. Surface sampling was conducted at four locations--in the middle of the lake and at three littoral stations along the western shore (Figure 1). At Squaw Lake and Myrtle Lake the water column was sampled in 20 and 8 m of water respectively. The ponds were sampled near their outlets, and only surface water was collected for analysis.

1) Field sampling. A temperature profile was taken at all but the Squaw Lake littoral stations. At the surface, separate water samples were collected for chemical analyses and for determining

dissolved oxygen, chlorophyll, and particulate matter concentrations. When stratification existed in the two lakes, additional samples were taken with a Van Dorn water bottle at the top, middle, and bottom of the metalimnion and the middle and/or bottom of the hypolimnion. During winter months samples were taken at 5-m (Squaw) or 2-m (Myrtle) intervals. Samples for chemical analysis were acidified (1 drop concentrated H_2SO_4/100 ml) to prevent nitrogen loss (as NH_3) and were then frozen. Determinations of chlorophyll and particulate matter were made within 12 hours of sampling.

The level of Squaw Lake was monitored with a staff gauge located near the north end of the lake. The water level at the two ponds was monitored by recording the water depth when routine limnological sampling was accomplished. No attempt was made to monitor water-level fluctuations in Myrtle Lake.

2) Laboratory analyses. The concentrations of chlorophylls and their decomposition products (phaeopigments) were determined spectrophotometrically using the level II procedure of Golterman (1969). Blank readings at 750 mm were not normally taken, but occasional checks indicated that there was little interference from turbidity or color. Chlorophyll extractions were made from glass-fiber filters treated with 90 percent acetone and ground in a tissue grinder.

Particualte matter concentrations were estimated from the weight of materials retained on glass-fiber filters. Known volumes of water were filtered through pre-ashed, pre-weighed filters. After drying for 12 hours, the filters were weighed, again ashed (at 500^{o}C for one hour), and reweighed. Concentrations of particulate matter were calculated as follows:

$$(4.7)\quad \text{Particulate matter/liter} = \frac{W_{60}-W_f}{V_f}$$

$$(4.8)\quad \text{particulate organic matter/liter} = \frac{W_{60}-W_{500}}{V_f}$$

$$(4.9)\quad \text{particulate inorganic matter (ash)/liter} = \frac{(W_{60}-W_f) - (W_{60}-W_{500})}{V_f}$$

where; W_f = weight of the filter,

W_{60} = weight of the filter after filtration and heating at $60^{\circ}C$,

W_{500} = weight of filter after heating at $500^{\circ}C$,

V_f = volume of water filtered.

Precision in weighing was $\pm$ .1 mg.

Dissolved oxygen concentrations were determined by a modified Winkler method (Golterman 1969, level II). Specific conductance (reported at $25^{\circ}C$) was determined on one of several meters that were checked to assure that standardized values were obtained. Additional chemical analyses were conducted on the acidified, frozen samples at the Research Analytical Laboratory. Calcium, Mg, and Fe were determined by atomic absorption spectroscopy. Total P was determined in the manner already described for throughfall. Nitrate plus nitrite (expressed as NO_3^-) and NH_4^+ were determined on the Technicon Autoanalyzer II. Methods are those of E.P.A. (1971). Total Kjeldahl N was determined by the method of Warner and Jones (1970). In this technique NH_3 and most organic compounds (including amino acid, proteins and peptides but not including NO_3^- and NO_2^-) are analyzed as NH_4^+ on the Technicon Autoanalyzer following hot digestion with H_2SO_4.

b. Streams. Squaw Lake is fed by six streams, which contribute water in varying amounts, primarily in the spring. The streams shown on Figure 2 have been designated PST, BST, MST, SWST, SST, and SEST. PST bisects the treatment area and drains Pond South. It was sampled most intensely. An H-type flume equipped with a water-level recorder was located at sampling station PST1. Also located at PST1 was an automatic water sampler (constructed according to specifications in Doty [1970]). The sampler filled a 250 ml bottle every 24 hours. The bottles from the water sampler and the charts on the water-level recorder and the recording rain gauge were serviced every 6-8 days between April and November. At the same time, additional water sampling was done at PST1 and at two other stations (PST2 and PST3) on PST. When no water was flowing through the flume at PST1, sampling was accomplished farther up the stream channel. Frequently during summer, the flow of water in all the streams feeding Squaw Lake was restricted to the upper reaches of the streams' channels.

Stream sampling included: water temperature, dissolved oxygen, conductivity, and total P analysis. Analysis for NO_3^- was performed on samples from PST1. Methods were as described earlier under limnological sampling except for NO_3^- which was analyzed by the Brucine method (APHA 1971) in 1973 and 1974. Samples from PST1 were also analyzed for total particulate matter (TPM), particulate organic matter (POM), and particulate inorganic matter (PIOM). Samples of known volume (usually 200 ml) were evaporated in pre-weighed crucibles. Crucibles were again weighed, ashed at 500°C for four hours and re-weighed. Particulate matter concentrations were calculated using weight loss after drying and ashing and are expressed as mg/l.

The other streams flowing into Squaw Lake were occasionally sampled near their outlets. They were sampled intensively only during the spring of 1975, when all streams were sampled in order to get comparative information on sediment transport to Squaw Lake.

In addition to inlet streams, Squaw Lake's lone outlet (Gould Creek) was sampled within several feet of where it left the lake. Gould Creek was sampled on the same schedule as PST1 and for the same parameters (except NO_3^-, which was not determined, and particulate matter, which was determined only during the spring of 1975).

Discharge for all streams was determined with a current meter. The flume was calibrated and a rating curve for Gould Creek was constructed, with stage height of Squaw Lake as the independent variable and discharge as the dependent variable. Flow for the other streams was generally determined when other parameters were sampled. Flow rates at BST, PST2, and PST3 were not determined, because stream-bed characteristics precluded accurated measurement.

c. Groundwater. A detailed characterization of ground water in the Squaw Lake watershed was not attempted. Two groundwater samples were analyzed, however, and the results of these analyses are important to the evaluation of the water budget of Squaw Lake. In October 1974 water was taken from a well near the southeast end of the lake and from a seep on Gould Creek north of the lake. Analyses were performed for the following parameters; total P and $PO_4^{=}$, NO_3^{-} and Kjeldahl N, conductivity, Ca, Mg, and Fe. Analysis methods were the same as for lake-water samples.

V. RESULTS

Data from all sampling at Squaw Lake can be placed in two categories: 1.) those that are relevant almost exclusively with respect to the parameters for which they were collected, and 2.) those for which interpretations are meaningful chiefly when combined with interpretations of data from other parameters. Although all data are presented here, only those of the former category are discussed in detail. Those of the second category will be discussed in the following chapter.

A. Paleoecology

Many types of disturbances undoubtedly affected Squaw Lake and its watershed prior to the late-19th Century arrival of white settlers. Only the occurrence of fire, however, has been well documented. Little is known of the spatial and temporal importance of wind storms. Despite the fact that tornadoes and destructive winter sleet storms undoubtedly occurred, such disturbances are probably relatively less important in Minnesota than in New England, where researchers have found that hurricane-force winds have significantly affected forest development (Stevens 1956, Henry and Swan 1974, Oliver and Stevens 1977). Studies to determine the effects of wind storms require detailed investigations of relatively small areas and have not been attempted in Minnesota.

1. Fire history. A summary of fire occurrence on the study area is presented in Table 1. Data are taken from Frissell (1971), who examined a pine stump near the southeast corner of Squaw Lake and two

Table 1. Summary of fire occurrences at Squaw Lake, 1702-1922.

Fire date	Extent (from Frissell 1971)	Notes
1702	Unknown	Frissell found five trees in the park with scars dating to 1702. The Squaw Lake sample tree was among them.
1727	Almost the entire northern ½ of the park including Squaw Lake.	But evidence indicates that the fire did not burn near the western shore of Squaw Lake.
1759	The western 1/3 of the park including Squaw Lake plus the area between the arms of Lake Itasca.	
1772	The entire park.	
1787	Unknown	***, but a sample tree approximately 1.6 km east of Squaw Lake is scarred.
1796	Only the NW ¼ of the park plus a small area south of Lake Itasca's east arm	But no evidence was found for this fire west of Squaw Lake.
1803	The entire park including the Squaw Lake area.	
1811	Only the area south of SWST and south and SE of Squaw Lake, plus most of the southern ½ of the park.	Additional evidence indicates that most of the area surrounding Squaw Lake was burned.

Table 1. Continued.

Fire date	Extent (from Frissell 1971)	Notes
1820	2/3 of the park including all of the area around Squaw Lake.	
1864	Almost the entire park including the area around Squaw Lake.	
1885	2/3 of the park including most of the area around Squaw Lake.	***, the reason for Frissell's including the area west of Squaw Lake is not clear, but evidence shows that the fire may have burned there.
1891	SE and east sides of the park plus a small area 2-3 km NE of Squaw Lake.	***, but much of the jack pine west of Squaw Lake dates from 1892-1995, and most of the stumps along the shore of Squaw Lake appear to bear a scar of about this date.
1895	East side of park but a stand 2 km east of Squaw Lakes dates from this year.	
1907	Only the area south and SW of Squaw Lake.	***, but fire scars on jack pine indicate that the area west of Squaw Lake also burned.
1909	---	***, a fire scarred sample tree is 2 km east of Squaw Lake.
1911	East side of the park plus an area east of Squaw Lake	***

Table 1. Continued.

Fire date	Extent (from Frissell 1971)	Notes
1917	Extreme eastern portion of the park.	***, but a fire scarred sample tree 2 km SE of Squaw Lake and fire scars on jack pine indicate that the area west of Squaw Lake also burned.
1922	---	***, Frissell identified only one scarred sample tree that was 2 km east of Squaw Lake. Scars on jack pine plus stand origin data indicate that this fire burned west of Squaw Lake but not to the north.

***indicates that Frissell's Squaw Lake sample tree had no scar for this year.

sample trees approximately 2 km SE and 2 km east of the lake. Frissell apparently examined neither the pine stands SW and N of Myrtle Lake nor the stumps of pine found along the west shore of Squaw Lake.

Frissell's data provide a generally accurate picture of fires that have occurred near Squaw Lake. The most significant corrections resulting from my work deal with his use of SWST as a fire break and the occurrence of fires during the late-19th and early-20th centuries. To add information on these two aspects, sections of six pine stumps cut about 1915 and several stumps of jack pine cut in 1974 were examined.

a. Red pine. The six pine-stump sections provide information on fires that burned the western shore of Squaw Lake between 1700 and 1900. Data are summarized in Table 2. All stumps are of red pine and are within 30-40 m of the lake. Three (stumps A-C) are close together and in plot R3. A fourth stump (D) is located midway between plot R3 and the mouth of PST. Stump E is near the flume on PST, and the sixth stump (F) is located just north of BST. Because the stumps are close to the shore of the lake, all were probably scarred by fires that burned from the west, southwest or northwest. The land slopes steeply toward the lake along its entire western shore, and it is possible that fires burning toward the lake were reduced in intensity by the cooler, east-facing aspect. Also, fires burn less rapidly down slope than up slope. On the basis of the abundance of cut pine stumps, the shores of Squaw Lake appear to have been more heavily timbered than the higher land to the west. Reduced fire intensity resulting

Table 2. Results of stump section analyses.

Section	Fire Dates Positive	Fire Dates Probable	Pith Origin
A	1759, 1772, 1803, 1811, 1864	1820, 1891	?
B	1759, 1772, 1803, 1811, 1820, 1865		1720
C	1759, 1772, 1803, 1865	1891	ca. 1720
D	1772, 1803, 1820, 1864	1759, 1811	ca. 1721
E	1759, 1772, 1803, 1811, 1820, 1864		?
F	1759, 1772, 1803 1820, 1865	1891	1728

from both microclimatic and terrain conditions may account for this.

Complete sections (including the pith) were recovered only from stumps B, C, D and F. Recovery of the outermost portion of the stump sections was difficult because preservation was generally poorest at the outer edge of the stump. This fact, combined with the formation of extremely narrow rings just prior to logging, limited the usefulness of the stumps in identifying fires that occurred after about 1890.

Additional information was gained by examining living trees. A red pine in the SW/SW, Sec. 6 was cored, and it apparently originated between 1815 and 1818. Frissell's maps indicate that this area was burned in 1796, 1803, and 1820, but not in 1811. The origin of the cored tree suggests that the area may have been burned in 1811 but probably not in 1820. Fire scars and narrow rings at about 1864 and 1907 indicate that this area was burned at least in these years. A second red pine (near plot V) was cored. This tree originated about 1874 and has narrow rings in the early 1890's. Frissell identifies 1875 as a year when much of the eastern part of the park was burned, and portions of the Squaw Lake watershed may also have burned then.

b. Jack pine stumps. The reconstruction of the occurrence of fire during the period 1890-1925 is difficult because most of the fires of this period were started in conjunction with land-clearing activities. As a result, the fires appear to have burned with no predictable pattern. Instead they probably occurred where slash had built up as a result of logging or in areas burned by homesteaders who were attempting to clear land for farming. Much of the forest around Squaw Lake was established during this period, and an examination of stand-origin data proved fruitful. This is especially true of the jack pine cut in 1974, for many of these trees bore fire scars.

Nearly 1700 fresh jack pine stumps were examined. The number of fire scars on each stump was recorded as well as the tree's status (living or dead) prior to logging. A summary of the data is found in Table 3. Data are presented for four separate areas (see Figure 3). Several stumps bore one or more scars, and the ages of some were determined. A distribution of the fire dates determined in this way is depicted in Figure 4. Stump sections were not made, and the cuts were not always smooth. Thus an error of ±1-2 years seems likely, and this probably accounts for the dispersion on Figure 4. A pattern is evident, however, and stand-origin data were used to verify suspected fire dates.

The jack pine stands west of Squaw Lake appear to have originated in the early to mid 1890's. Stump dating plus the boring of 7 trees each in plots J and W (in 1973) indicate that most trees had 75-77 annual rings at 30 cm above the ground. The addition of three years for seedling growth provides a stand origin date of ca. 1894. This date suggests a major fire for the area in the early 1890's. The outside fire scars on several of the red pine stump sections near Squaw Lake date to this period and indicate that the fire probably burned to the western shore of the lake. Frissell's maps show no fire in the vicinity of Squaw Lake at this time but do show a fire that burned northeast of the lake in 1891. It is possible that

Table 3. Summary of fire scar data for jack pine cut in 1974.

Category	Area 1 No.	Area 1 % of Total	Area 2 No.	Area 2 % of Total	Area 3 No.	Area 3 % of total	Area 4 No.	Area 4 % of total
Total trees scarred	71	22.0(23.5)	129(133)	12.9(13.3)	41	24.1	7(8)	3.6(4.3)
1 scar	65(3)	20.1(21.1)	90	9.0	41	24.1	7	3.8
2 scars	6(2)	1.9(2. 5)	39(3)	3.9(4.2)	0	---	0(1)	---(0.5)
3 scars	0	---	0(1)	---(0.1)	0	---	0	---
Total live trees checked	278	86. 1	863	86.0	125	73.5	140	75.2
Total live trees scarred	55 (60)	17.0(18.6)	96 (100)	9.6(10.0)	24	14.1	5 (8)	2.7(4.3)
Total dead trees checked	45	13.9	139	13.8	45	26.4	46	24.7
Total dead trees scarred	16[1]	5.0	33[2]	3.3	17[3]	10.0	2[4]	1.1

1 35.6 percent of all dead trees

2 23.7 percent of all dead trees

3 37.8 percent of all dead trees

4 4.3 percent of all dead trees

a 19.8 percent of all live trees

b 11.1 percent of all live trees

c 19.2 percent of all live trees

d 3.6 percent of all live trees

Values in ( ) are possible scars

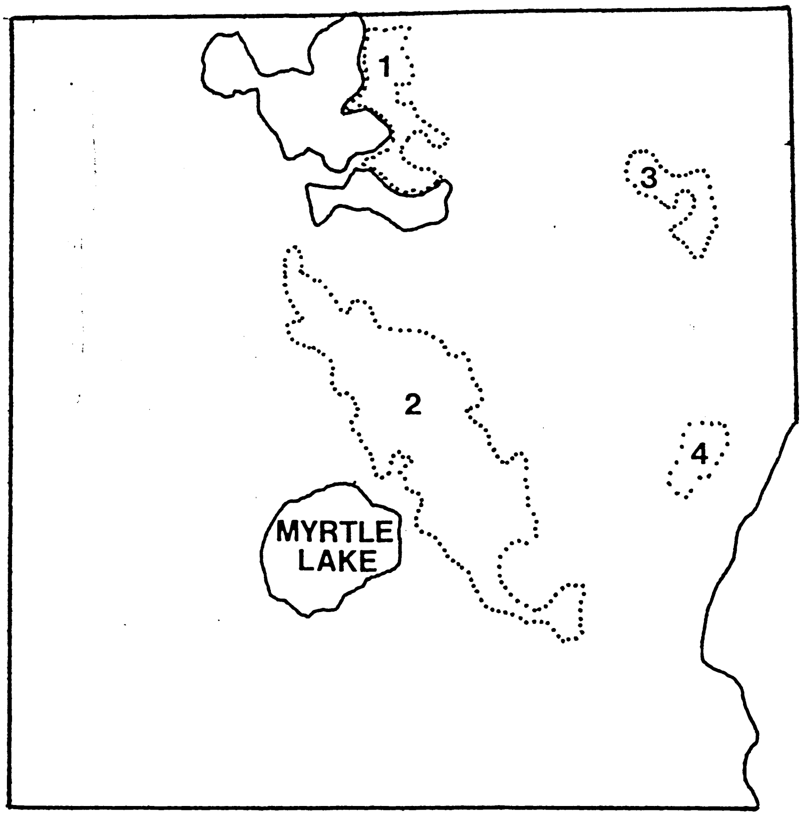


Figure 3. Map of areas surveyed for jack pine stump scars.

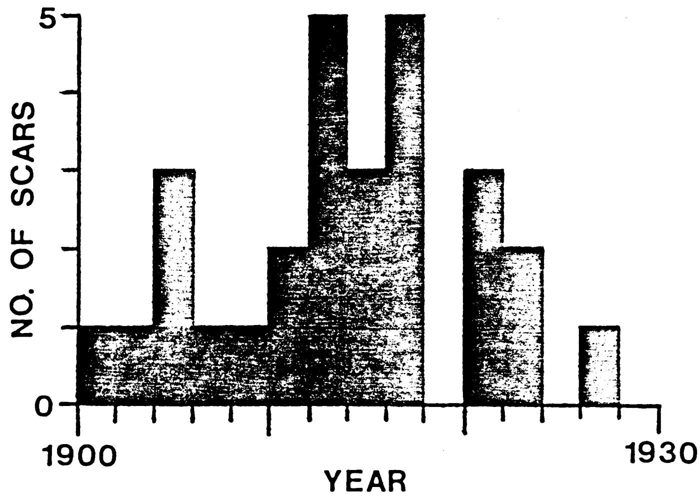


Figure 4. Distribution of fire-scar dates for jack pine cut in 1974.

Frissell's stump section (from a tree logged in the early 20th Century) was missing the outermost fire scar. This would account for his failure to recognize the occurrence of the 1891 fire at Squaw Lake.

The dates of origin of other stands west of Squaw Lake are shown in Table 6, p. 97. Although somewhat imprecise these data suggest that most stands originated during the following periods; 1907, 1910-1915, 1918-1922, and 1922-1928. According to these dates, the data presented in Figure 4, and other field observations, I have concluded that fires probably burned somewhere in the Squaw Lake watershed in 1910-11, 1917-18, and 1922. Frissell recorded fires within 2 km of Squaw Lake in 1911, 1917, and 1922.

The Squaw Lake shoreline near plot R3 apparently did not burn after 1917. The second growth pine at R3 dates from 1915 (immediately after logging), and the seedlings would have been destroyed if the area had been burned. The area north of Squaw Lake may not have been burned after 1907. Recently-logged jack pine from that area date from about that time and have no fire scars.

Ness (1971) sampled two stands in the vicinity of Squaw Lake, and his results can be used to add information on the occurrence of fires between 1890 and 1925. A stand in the NW¼, Sec. 18, T.143N.-R.36W. contains trees that apparently regenerated after fires in 1864, 1891, 1909, 1911, 1915, and 1918. Another stand northwest of Squaw Lake in the NW¼, Sec. 5, T.143N.-R.36W. contains trees in age classes that indicate the area was burned in 1909, 1911, and 1922.

Between 1895 and 1910, major fire years on a statewide basis can be identified by examining the Annual Reports of the State Fire Warden.

Data are summarized in Table 4. The years 1900, 1905, 1908, and 1910 stand out as major fire years. Frissell identifies only 1905 as a fire year for Itasca State Park, but his fire years of 1899, 1907, 1909, and 1911 could be off by one year. Frissell shows a burn area south and southwest of Squaw Lake for 1907, but his use of SWST as a fire break is not substantiated by evidence from scarred trees.

It seems likely that the area occupied by 77-year-old jack pine logged in 1974 was not burned before 1907, for trees less than 12 years old probably would not have survived a fire. It is somewhat remarkable, in fact, that some apparently did survive as many as three fires before they reached 30 years of age.

c. Summary. The intensive survey of the area around Squaw Lake allows updating of the history of the occurrence of fire as presented by Frissell. Major fires appear to have burned at least a portion of the Squaw Lake watershed in 1759, 1772, 1796, 1803, 1811, 1820, 1864, and ca. 1891. Fires associated with land clearing occurred about 1907, 1910, 1918, and 1922. Much of the virgin red pine surrounding Squaw Lake in 1900 regenerated between 1710 and 1730, and it seems likely that one or more major fires burned the area in the early 18th Century. Some corrections have been proposed for Frissell's maps, but I have not attempted to redraw them. The construction of fire maps for areas as large as a township are roughly correct when portions of the township not smaller than a section are compared. Detailed mapping within a section is more difficult, and the construction of a map for the Squaw Lake area would have been most difficult.

Table 4. Summary of data from the Annual Reports of State Fire Warden for the years 1895-1910.

Year	Forest Acres Burned
1895	8,265
1896	14,912
1897	66,020
1898	21,580
1899	3,635
1900	179,521
1901	58,395
1902	18,285
1903	15,585
1904	21,920
1905	102,968
1906	11,561
1907	10,385
1908	405,748
1909	45,690
1910	1,051,333

Although this discussion emphasizes the occurrence of fire, the length of intervals when no fire occurred is important. It is significant that the longest of these is 52 years (from 1922 to 1975). Since 1700, the only period that approaches this length is that between 1820 and 1864. State fire-prevention efforts effectively excluded fire from the area until 1975, when about one-half of Section 6 was burned for management purposes.

2. The impact of European man.

a. Settlement. French and English explorers first entered the Itasca area in the late-18th and early-19th Centuries, but it was not until 1832 that H.R. Schoolcraft officially determined that Lake Itasca is the Headwaters of the Mississippi River (Dobie 1959). Dobie notes that Edwin S. Hall conducted the official land survey for the area in 1875, and by 1883 settlers began establishing homesteads on the shores of Lake Itasca.

One of the first published maps showing Squaw Lake appears on p. 268 of Brower's Itasca State Park. An Illustrated History. The map is entitled "Ojibway Indian map of Itasca Lake, 1881" and shows four small lakes west of Lake Itasca. The eastern most of these has an island and is undoubtedly Squaw Lake, the others being Long, Heart, and Sucker. There apparently was an early controversy over the naming of Squaw Lake and Brower refers to it as McMullan Lake "to discriminate against the vulgar notions of ignorant and illiterate timber cruisers" (Brower 1904, p. 52). Brower later notes (p. 279) that "the name McMullan Lake, in honor of William McMullan has been supplanted on the government chart of 1900 by 'Squaw Lake', more than the tenth time for that name on various lakes in the northwest."

The first record of settlement at Squaw Lake is found in the official Record of Deeds for Clearwater County. On October 6, 1881 H.A. Jewett obtained the homestead rights to the SE/NE and lot 8, Sec. 6. The notation in the Record of Deeds indicates that 75.75 acres of land were involved, but, when Jewett sold the SE/NE and lot 8 to N.P. Clarke less than three months later for $100.00, the Record of Deeds indicates that only 70.75 acres were involved. This would indicate that Jewett retained 5 acres, although no further entries were found that identify Jewett as owning this land. During field reconnaissance I found, on lot 8 near its boundary with lot 9, the remains of a cabin including a stone foundation, an iron stove, and several bottles and cans. The foundation is about 50 m west of the shore of Squaw Lake and is in an area with many red pine stumps. It is possible that this is the site of Jewett's homestead, and, if it dates from 1881, it is the oldest recorded homestead site within the present boundaries of Itasca State Park. The foundation of a second cabin was located east of the first, near the shore of Squaw Lake. The cabin is faintly visible in a picture taken of Squaw Lake about 1913 by T. Shantz-Hansen (Plate 1), and this also could have been the site of Jewett's cabin. The structure is, however, smaller than the one farther up the hill, and its existence in 1913 suggests that it may have been used in conjunction with the logging of lot 8 (during 1905-07).

N.P. Clarke was associated with the Nicholas and Chisholm Lumber Co. of Frazee. This company logged most of T.143N.-R.37W. between 1910 and 1920. In 1888 Clarke sold the 70.75 acres he purchased from Jewett to T.B. Walker, however, and the land was eventually logged by Walker's Red River Lumber Co.

Several other tracts of land were homesteaded in the Squaw Lake area in the years following Jewett's first claim. Because of the steep terrain and stoney soil, most of these claims apparently were for the purpose of exploiting the dense stands of timber around the lake and not for establishing farms. A few hunting camps were erected in the northern portions of Sec. 6 and near Myrtle Lake (where Myrtle Cummings established a homestead claim in 1904). The most significant activities associated with the settlement period were, however, those of major logging companies including the Brainerd Lumber Co., the Pine Tree Lumber Co. of Little Falls, and Walker's Red River Lumber Co.

b. Logging. Dobie (1959) provides a generalized account of logging activities in Itasca State Park. Although some salvage logging has occurred in the park since 1919, the major logging period was from 1901 to 1919. Aaseng (1976) estimates that 39 percent (11,573 acres) of the park was "cut over" and an additional 5 percent (1,536 acres) was "partially cut over" during this 18 year period. Much of the logging was in the western one-third of the park including all of the land within 1 km of the shore of Squaw Lake.

From Dobie's account it is clear that the logging around Squaw Lake occurred during two distinct periods three to four years long. He notes that Barnard and Gorder camped at Squaw Lake during the winter of 1904-1905 and logged 10 million board feet of timber for the Red River Lumber Company. The logs were landed in Squaw Lake and subsequently hauled by rail to the mills. Later, between 1914 and 1917, George Wilson camped at Squaw Lake and logged Weyerhaeuser lands in the area.

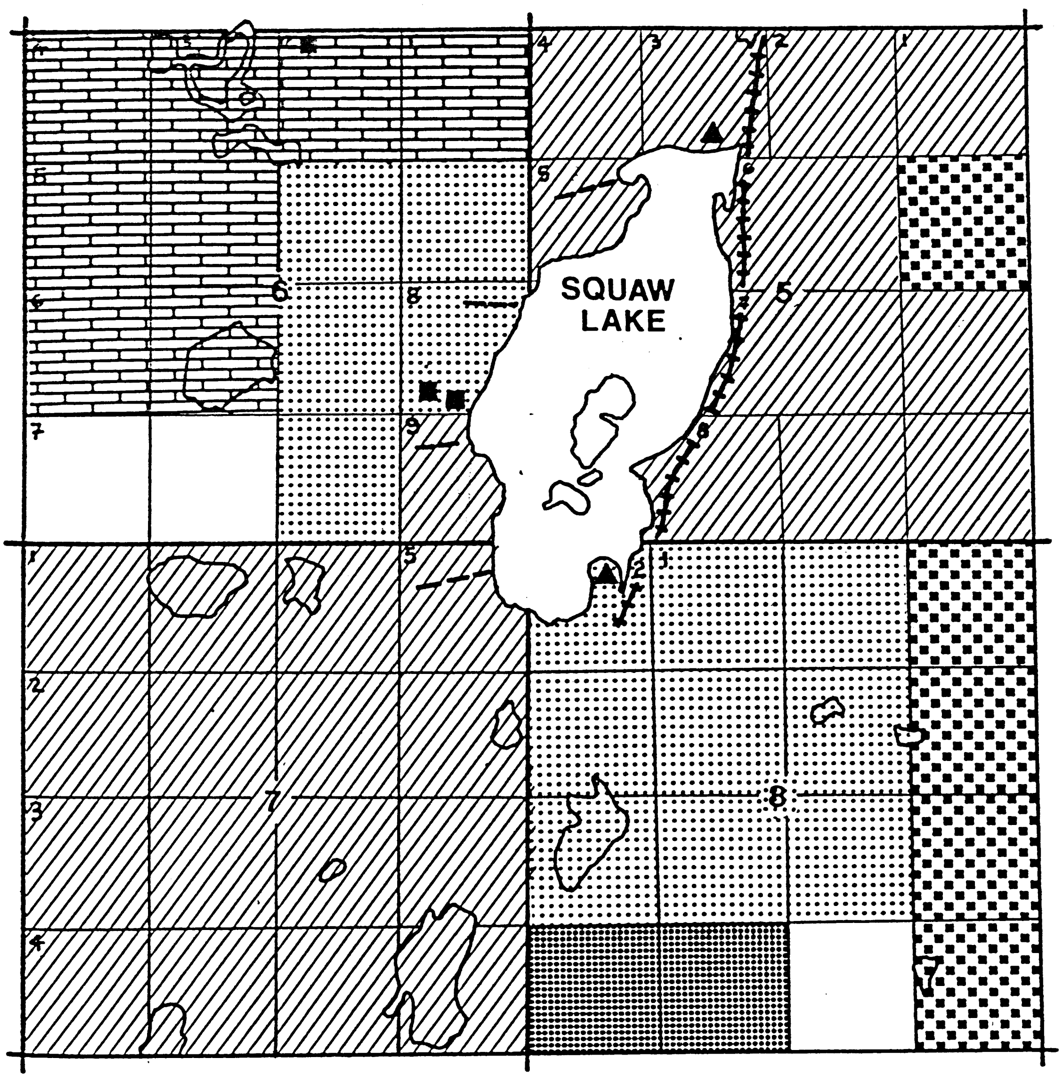
Dobie provides few other details of the logging around Squaw Lake and indicates that many of the records associated with logging activities were lost or destroyed. As part of my studies, I tried to obtain more specific information, especially with respect to lands logged during the two periods mentioned above. I was originally assisted in this effort by N.E. Aaseng, who eventually expanded the study to the entire park (Aaseng 1976). Only Aaseng's methods and those results specific to the Squaw Lake area are summarized here.

Dobie (1959) frequently refers to the ownership of logged-over lands, and we felt that an analysis of land-ownership transactions might indicate years when tracts of land were logged. This proved to be the case. Nearly half of the western one-third of Itasca State Park, including all of Sec. 7 and much of Sec. 5, was purchased by Frederick Weyerhaeuser and two associates in 1891. A total of 4,837.16 acres was obtained from the Northern Pacific Railroad for about $1.60/acre. About the same time, T.B. Walker (and his Red River Lumber Company) purchased nearly one-third of Sec. 6 and more than half of Sec. 8. Other owners of land near Squaw Lake were the Brainerd

Lumber Company (associated with C.A. Pillsbury), which owned portions of Sections 4, 5, and 8, and Myrtle and L.S. Cummings, who homesteaded lots 1, 2, 3, 4, 5, and 6 and the NE/SW and SE/NW of Sec. 6 in 1904-1905. The land north of Squaw Lake (Sections 31 and 32, T.144N.-R.36W.) was owned at least in part by T.B. Walker and the Red River Lumber Co. Most of the land around Squaw Lake passed through several owners, and those mentioned above are the ones believed to be owners of record at the time of logging.

Aaseng (1976) tabulates, on each forty-acre area, the logging that occurred in Itasca State Park. Information pertinent to the Squaw Lake area is depicted graphically in Figure 5.

The first logging camp at Squaw Lake was built on a point of land in the southeast corner of the lake. There has been some confusion over the camp's builder and its dates of operation. Dobie (1959) states that Barnard and Gorder maintained the camp during 1904-05 and logged for the Red River Lumber Co. He also states that a railroad between the logging town of Mallard and Squaw Lake was completed in 1903. Aaseng's research, however, indicates that Barnard and Gorder logged for the Brainerd Lumber Co. Furthermore, the Bemidji Daily Pioneer of August 28, 1906 states that the railroad to Squaw Lake had not yet been completed. The paper reports that 12 million board feet of timber owned by the Red River Lumber Co. were in Squaw Lake at the time. These logs apparently were cut the previous winter. We located the remains of a logging camp in lot 2, Sec. 8. In 1905 this land was owned by the Red River Lumber Co., and it would appear that Dobie is not correct in calling this the Barnard and Gorder camp. There is no



Brainerd Lumber Co., 1902-1904

Brainerd Lumber Co., 1904-1906

Red River Lumber Co., 1906-1908

Pine Tree Lumber Co., 1915-1917

unknown, ca. 1908-1913

Cabin

Logging camp

Haul road

Railroad

Figure 5. Summary of logging operations at Squaw Lake, 1902-1917.

record of who actually logged for the Red River Lumber Co. at Squaw Lake, however, since T.B. Walker's files for the period were destroyed by vandals (Dobie 1959). Barnard and Gorder may have operated out of a camp known to have been maintained by the Brainerd Lumber Co. in Sec. 30, T.143N.-R.36W.

Figure 5 shows that the area around Squaw Lake was logged between 1906-08 (by the Red River Lumber Co.) and between 1915-17 (by the Pine Tree Lumber Co.). Connor and Wilson logged for the Pine Tree Lumber Co. and operated a camp at the outlet of Squaw Lake.

There is no record of when the land owned by L.S. Cummings in Sec. 6 was logged, but Myrtle (Heinzelman) Cummings sold a Warranty Timber Deed for her lands to J.S. Richards on Nov. 16, 1908. The contract specifies that Cummings was to receive $2,000 and that the timber was to be removed within 5 years. The lots owned by L.S. Cummings (1, 2, 3, and 4) contain cut stumps and probably were logged about the same time, perhaps by Cummings himself.

There are no reports of the actual amounts of timber removed from individual lots and forties around Squaw Lake, but information compiled from Dobie and Aaseng indicates that the lands were heavily timbered. Near the lake stocking apparently exceeded 250,000 bd ft on some forty-acre tracts. Brower and Finney surveyed the timber in the eastern two-thirds of the park in 1899 and found that the best pine lands averaged 200,000-300,000 bd ft per 40 acres, although a few tracts contained more than 600,000 bd ft. It is perhaps not unreasonable to estimate that the four sections around Squaw Lake contained 16 million bd ft or more of timber. In these four sections only three forty-acre tracts (S½,SW¼,Sec. 6 and SW/SE, Sec. 8) were left uncut. Farther from Squaw Lake, lands west of Sec. 6 were logged (ca. 1915) by the Nicholas & Chisholm Lumber Co., and most of the tracts north of Sections 5 and 6 were logged prior to 1910 by the Red River Logging Co.

All timber cutting was accomplished during the winter when sleds could be used to haul logs from the woods. During the spring and summer logs were driven or hauled to mills. New camps were also constructed during the summer, and roads were extended and upgraded. Logs were landed, sorted, and graded on Squaw Lake after being cut in the winter. They were then hauled to the mills by rail (1906-1908) or steam-driven tractors (1915-1917). During the latter period logs were hauled to the Mississippi River (north of the park) and driven to Bemidji. Logs cut by the Brainerd Lumber Co. were sawn in Brainerd, those by the Red River Lumber Co. in Crookston and Akeley, and those by the Pine Tree Lumber Co. in Little Falls.

c. Post-logging activities. After logging, much of the land around Squaw Lake was burned. Most of the cut stumps examined showed evidence of having been burned after the trees were cut. Prior to 1909 most slash was probably burned in the spring and summer after it had dried. In 1909, however, a state law was passed requiring slash be burned prior to May 1. This law attempted to reduce the extreme fire hazards posed by large quantities of dried pine boughs left after logging. Compliance with the law varied from one logging operation to the next, however, and fires continued to burn out of control until the logging of Minnesota's pine lands was completed in the 1920's.

The land around Squaw Lake was purchased by the state for park purposes between 1919 and 1928. A summary of these transactions is found in Table 5. Usually only the land was conveyed to the state. The Record of Deeds specifically notes that the Pine Tree Manufacturing Co. and the Clearwater Acres Co. retained mineral rights to the lands they sold.

Little is known of the land-use history around Squaw Lake between the time the area was logged and the time it was transferred to state ownership. Tax records indicate that the Cummings probably maintained a hunting camp on their property. There is no indication that farming was attempted on even a small scale, although Dobie (1959) notes that logging camps usually maintained a small amount of livestock.

After the state obtained the land around Squaw Lake, prevention efforts were successful in eradicating fire and most of the present forests developed in the absence of major disturbance. In 1932 a cabin was built at the north end of the lake near the site of the Connor and Wilson logging camp. Between 1934 and 1935 a transient work camp was operated at the southeast end of Squaw Lake by the Minnesota Emergency Conservation Work (Dobie 1959). This camp housed perhaps as many as 100 men at a time, but little is known of their activities, especially as they may have affected the forests around the lake. At some point a large deer exclosure was built in the NE¼ of Sec. 5, and it may have been constructed by camp crews. The Squaw Lake camp was quite large

Table 5. Transactions conveying land from private to state ownership in Sections 5, 6, 7, and 8, T.143N. - R.36W.

Date	Private Owner	Description	Price/Acre
31 July 1919	Pine Tree Manufacturing Co.	lots 1-8, NE/SE, and S/SE; Sec. 5 lots 1-5, W/NE, SE/NE, E/NW, E SW and SE; Sec. 7	$5.00
12 Oct 1927	Clearwater Acres Co.	SE/NE; Sec. 5 E/NE, E/SE; Sec. 8	$5.00
27 May 1925	L.S. Cummings	lots 1-4; Sec. 6	$1.00/ 157.54 acres
20 Sept 1921	M. (Heinzelman) Cummings	lots 5-6; SE/NW, NE/SW; Sec. 6	$5.00
20 Oct 1927	Red River Lumber Co.	S/NE, W/SE, lot 8; Sec. 6 W/NE, lots 1-2, S/NW, N/SW, NW/SE; Sec. 8	$5.00

and had well-developed fresh-water and waste-disposal systems. Of perhaps some significance to Squaw Lake is the fact that the sewage was disposed of in drain fields. The remains of underground drainways can still be found, and they lead almost to the shores of the lake. Squaw Lake may have been impacted by this drainage system when the camp was used most heavily in the 1930's. Use of the camp in recent years, however, has been limited to small groups for short periods of time. The lake itself is visited occasionally by pleasure boaters and fishermen.

In 1967 the Department of Natural Resources, in cooperation with the University of Minnesota, began a program to re-establish pine in the area around Squaw Lake. The logging and subsequent fires in the early 1900's resulted in the conversion of the area's vegetation from predominantly pine to aspen and birch. A small six-acre tract of aspen east of Squaw Lake was clearcut in the winter of 1967-68. Between 1970 and 1974 an additional 20 acres were cleared in the general vicinity of plot Z4. During January-March, 1974 the larger 113 ha area west of the lake was logged. Approximately 200 cords of jack pine, 2200 cords of aspen and 60 cords of birch (1,230,000 bd ft total) were removed. A small five-acre (2 ha) portion of the area (near plot J) was burned on September 18, 1974, and on May 12-13, 1975 another prescribed burn was conducted. Most of the area within the fire line (see Plate 2) was burned by the second fire. Burning was rather patchy in the north half, while the southwest section that contained large amounts of jack pine slash burned intensely.

3. The sedimentary record of land disturbance. All of the evidence for disturbance discussed to this point comes from land-based studies. Additional evidence was found in the sediments of Squaw and Myrtle lakes. The results of the sedimentary studies will be presented here, but they will be discussed in detail later, for the interpretations rely in part upon information from the neoecological studies.

a. Sediment characteristics. The sediments of the two study lakes are strikingly different in their physical appearance, chemical characteristics, and fossil content. This is not surprising, for the lakes are dissimilar. Myrtle Lake is much smaller (4.6 ha vs. 68.3 ha), is surrounded by more level topography, and is biologically much more productive than Squaw Lake. Myrtle Lake's sediments appear to be homogeneous, and analysis of their fossil contents indicates that mixing has disrupted the stratigraphy. Thus, although the fossil pollen content of small basins normally reflects adjacent vegetation most precisely, this apparent advantage has been lost at Myrtle Lake. Squaw Lake, on the other hand, has sediment bands (laminae) that indicate the sediments have been little disturbed since deposition. Two types of bands occur. The first are extremely fine (<1 mm wide) alternating layers of extremely dark and somewhat lighter sediment. These laminations occur regularly in portions of the core, but are not visible in other sections. They are only visible in the frozen core. Sediment bands of the second type are almost white, occur irregularly, and are clearly visible, even in the unfrozen core. Because of the apparent lack of mixing, the Squaw Lake core was sampled more intensively than the one from Myrtle Lake.

The most obvious characteristic of the Squaw Lake sediments is the occurrence of white bands that vary between 1 mm and 5-10 mm in thickness and occur throughout the upper .75 m of sediment. Bands in the upper, middle and lower one-third of the frozen core are shown in Plate 3. Determination of the origin of the sediment bands in Squaw Lake became a point of interest for bands of this nature are unusual and have not been reported for other lakes in the Itasca area. Bands like those in the Squaw Lake sediments have been reported by Edmondson (1977), who describes two distinct types in the sediments of Lake Washington in the state of Washington--those composed almost exclusively of diatoms and those composed of silt. The former are biogenic and autochthonous while the latter are composed of allochthonous material. A third type of white sediment band may be composed of marl. Marl bands form when calcium carbonate precipitates in hardwater lakes during summer months, when dissolved CO_2 levels drop as a result of increased phytoplankton and macrophyte productivity (Ruttner 1972). It is possible that such bands could become thicker and more pronounced in a lake that suddenly becomes more productive for some reason. Thus if the sediment bands in Squaw Lake were composed of marl, they could reflect increased productivity following disturbance. Elk Lake in the southern portion of the park contains annual marl bands, and Stark (1976) has hypothesized that the increased thickness of these bands in the early 20th Century may be attributable to increased productivity following logging in the watershed.

Plate 3. Upper (a), middle (b), and lower (c) one-third of the frozen sediment core taken from 24 m of water in Squaw Lake.

When the Squaw Lake 5-cm unfrozen core was sampled, notations were made when .5 cm samples containing white bands were encountered. These observations are recorded on lithologic diagrams on all figures that present analytical results. Figure 6 shows the particulate-matter content of the upper 42 cm of the Squaw Lake sediments. Separate curves depict total particulate matter (bulk density) as well as the organic and inorganic fractions. Peaks in total and inorganic particulate matter correspond closely to observations of sediment bands. These two fractions are significantly correlated (r=.99). The correlation between total and organic particulate matter, on the other hand, is lower (r=.56), and organic matter content does not increase in the bands. Because the samples were analyzed much later, curves for the 42.5-50 cm interval are not shown on Figure 6, although values are presented in Appendix A. Some drying of the samples occurred despite the fact that they were sealed in air-tight plastic containers.

Figure 7 depicts curves of percent organic matter and moisture for the sediments of Squaw Lake. Calcium carbonate values for selected Squaw Lake levels are also included in Figure 7. Myrtle Lake values are presented in Appendix B. The moisture content of Myrtle Lake sediments is uniform except near the sediment-water interface, where values rise from 92-93 percent to 98 percent. Values for Squaw Lake sediments are generally less than 90 percent below 12.0 cm and drop to as low as 65-75 percent in the bands. Organic matter content of Myrtle Lake is nearly uniform at 54-57 percent except between 2.5 and 10 cm, where values are 50 percent or less. Values for Squaw Lake are much

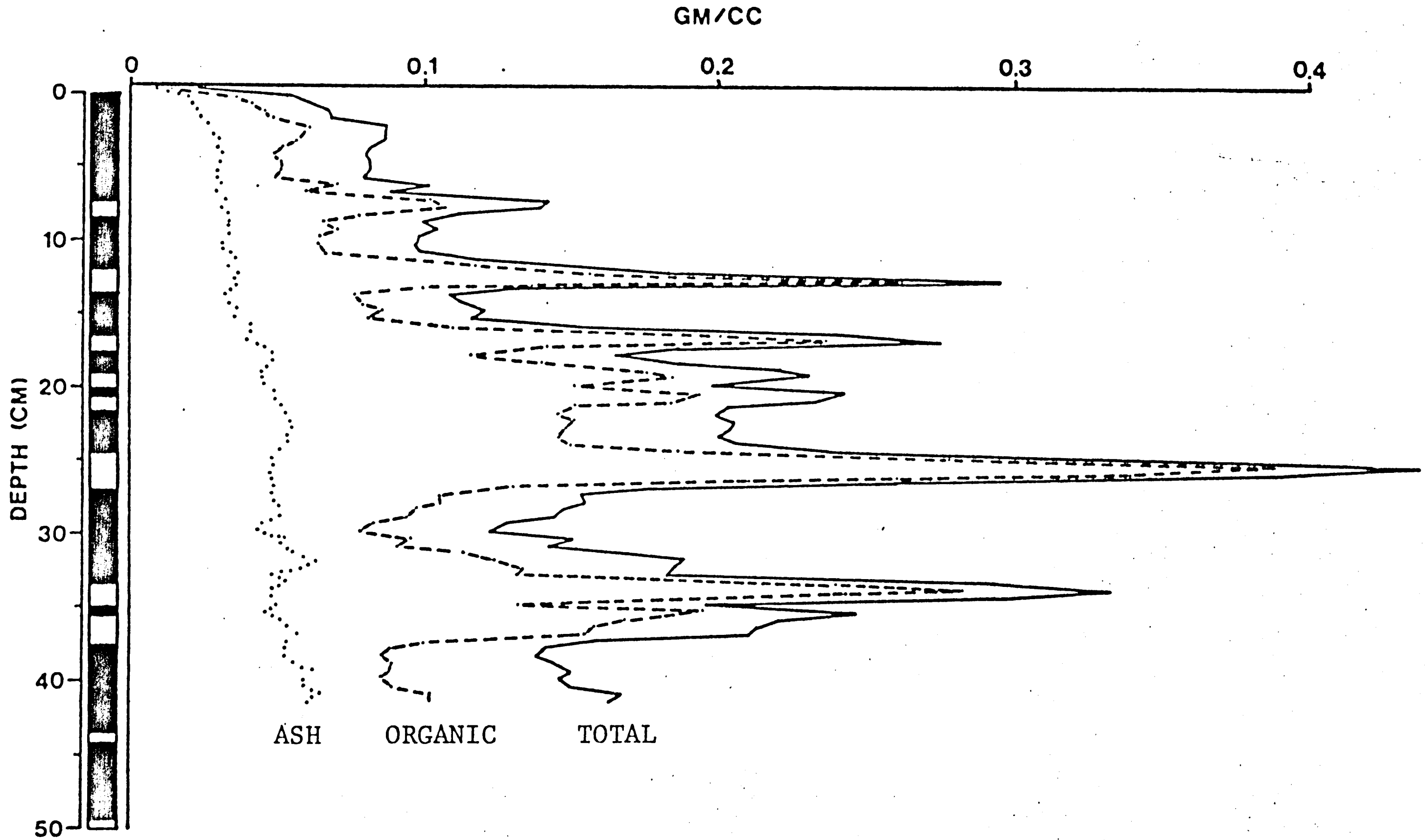


Figure 6. Particulate matter content of Squaw Lake sediments.

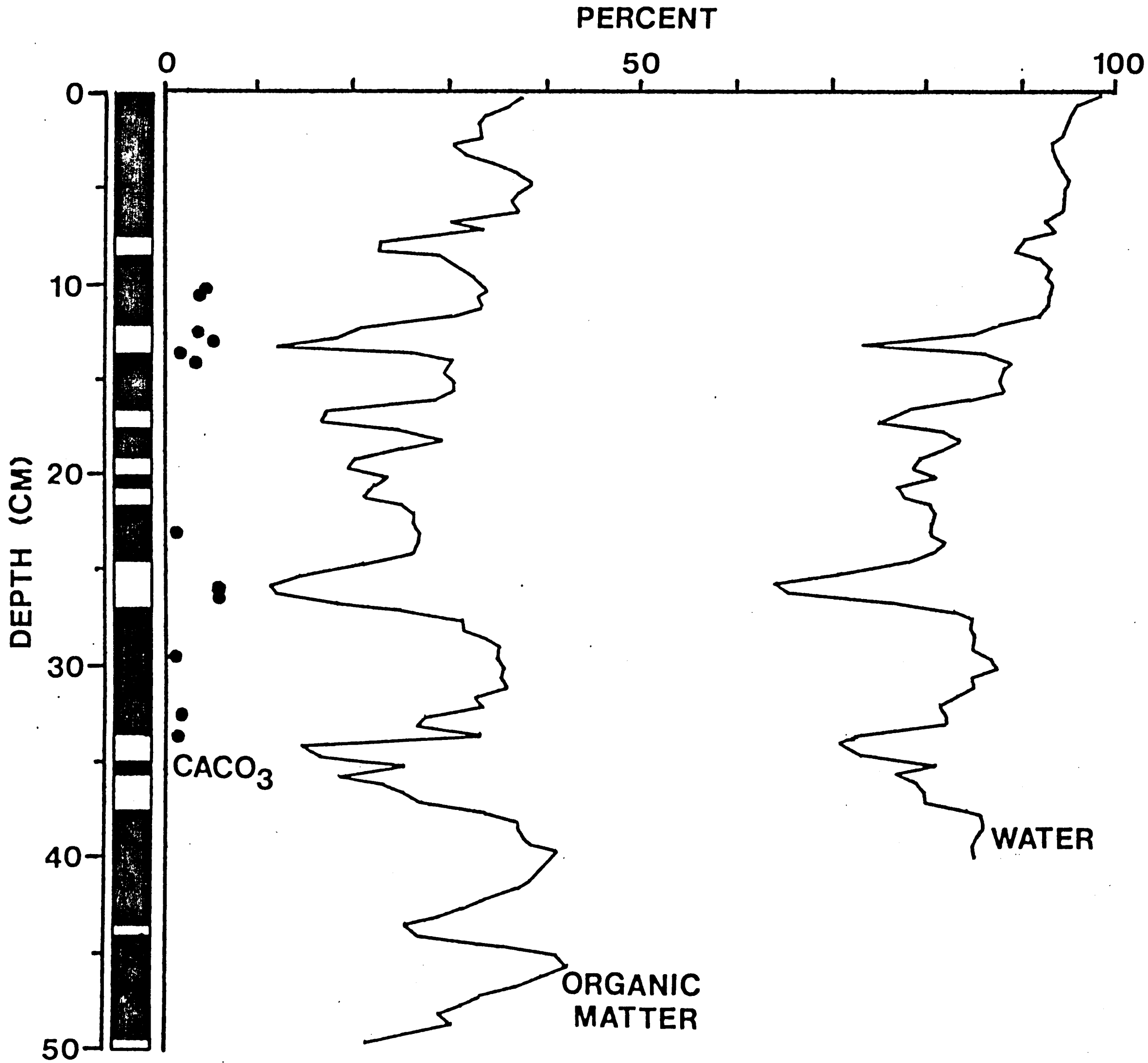


Figure 7. Percent organic matter, $CaCO_3$ and water for Squaw Lake sediments.

lower, falling to as low as 10-15 percent in some bands. Values as high as 40-43 percent occur between 40 and 50 cm, where several sediment parameters show unusual values. Calcium carbonate for Squaw Lake is typically 1-3 percent with the highest value (6 percent) in a band at 26 cm.

The values reported above can be compared with those of Bonnewell (1974), who sampled Itasca, Elk, Long, and West Twin lakes plus a small pond. She sampled surface sediments at different depths and found that percent organic matter generally increases with depth, whereas $CaCO_3$ content decreases. Marl content can be expected to decrease in sediments of deeper portions of lakes, for precipitating $CaCO_3$ redissolves when it enters CO_2-rich hypolimmetic waters (Ruttner 1972). The highest $CaCO_3$ value reported by Bonnewell was 90.3 percent for Elk Lake sediments under 2 m of water. Even at 19 m Elk Lake sediments contain more than 45 percent $CaCO_3$. Itasca sediments contain 30 percent (at 13 m) to 60 percent (at 3 m) $CaCO_3$, while Long Lake sediments have a uniform 55-60 percent $CaCO_3$ content. Only Bonnewell's smallest water bodies had $CaCO_3$ concentrations as low as Squaw Lake. Values at West Twin were about 12 percent, whereas those at the pond were 2 percent.

Organic-matter concentrations reported by Bonnewell are 16-29 percent for Lake Itasca, 5-21 percent for Elk Lake, 9-16 percent for Long Lake, 13 percent for West Twin, and 47 percent for the pond. Squaw Lake values are within the range of these lakes, whereas Myrtle Lake has values substantially higher.

The results of sediment chemical analyses for Squaw Lake and Myrtle Lake are presented in Appendix A and Appendix B, respectively. All concentrations are reported with respect to oven-dry weight. Figure 8 contains curves for P, Ca, and Fe in the sediments of Squaw Lake. For almost all parameters, Squaw Lake concentrations are higher than those in Myrtle Lake. This is especially true for P, Fe, and Mn.

Phosphorus concentrations in Squaw Lake sediments range from a low of .14 percent (at 25.3 cm) to a high of 2.37 percent at 44.3 cm. Concentrations of P in Myrtle Lake sediments are generally an order of magnitude lower and vary between .08 percent and .21 percent (at the sediment-water interface). Calcium concentrations in the sediments of both lakes average about 1.0 percent but rise to 1.5-2 percent in several of the Squaw Lake bands. Iron values for Squaw Lake are extraordinarily high in general but are also highly variable. Values range from 1.65 percent to 23.5 percent. Myrtle Lake values are all less than 1.0 percent. Manganese values range from .11 percent to .93 percent in Squaw Lake but are again an order of magnitude less in Myrtle Lake. Differences between the two lakes are not as dramatic for the other elements (Al, Mg, Zn, and B), although Squaw Lake values are generally higher. Values for Zn are usually high at the sediment-water interface in both lakes. Concentrations of 390 ppm (Myrtle Lake) and 860 ppm (Squaw Lake) are respectively two and four times higher than at any other point. Although I can offer no explanation for these high values, the fact that they occur in both cores argues against analytical error.

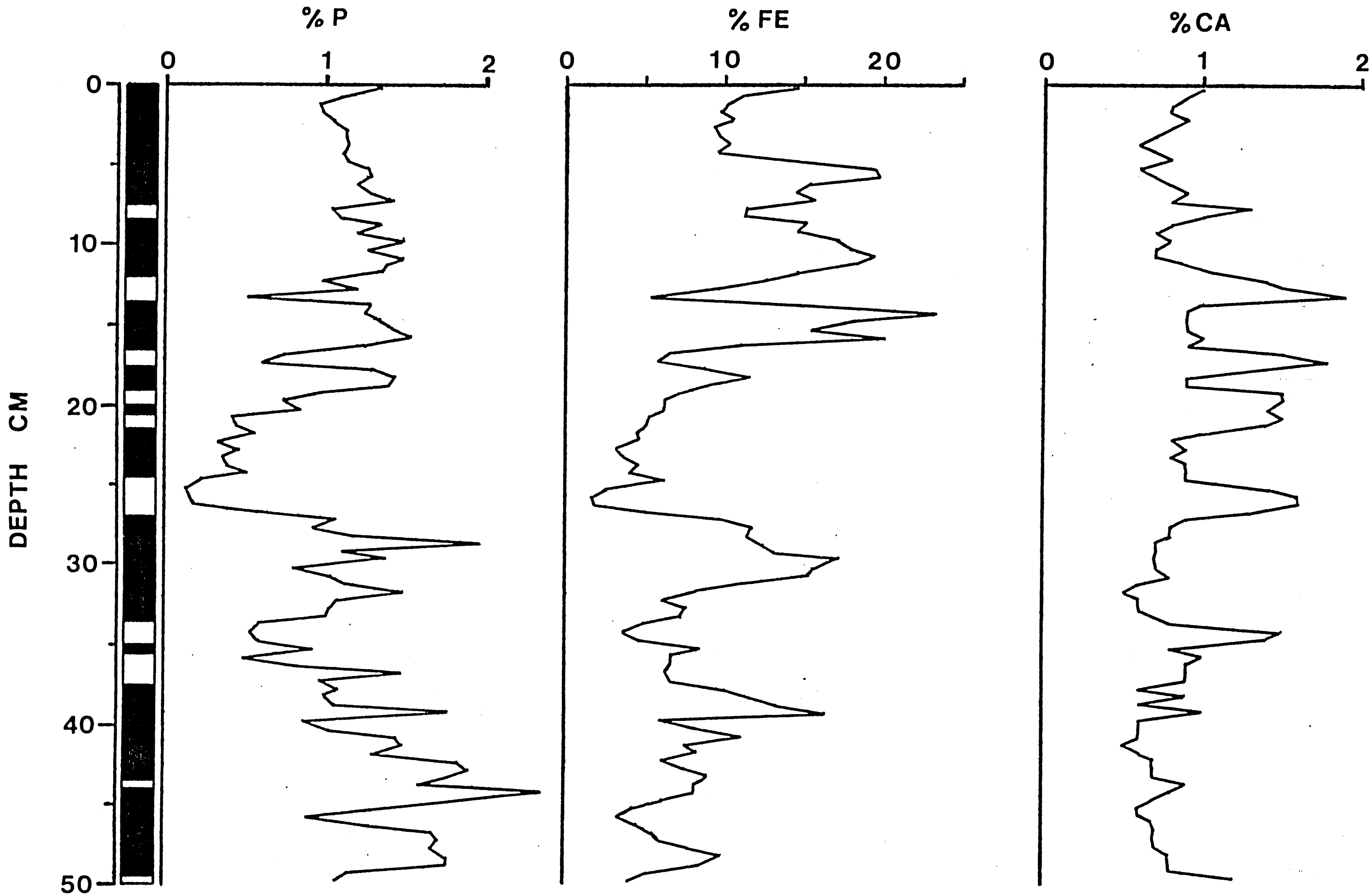


Figure 8. Percent P, Fe and Ca for Squaw Lake sediments.

Discussion of the results of the chemical analyses is made difficult by the fact that there have been no comprehensive studies of sediment chemistry for lakes in Minnesota. The few studies that have been conducted examined specific elements (usually P) and used a variety of digestion and analysis techniques. Some attempt must be made, however, to explain the extremely high values reported for most elements in the Squaw Lake sediments.

Swain (1966) discusses the geochemistry of several North American lakes, including some in Minnesota. For Cedar Creek Bog he presents data from Swain and Prokopovich (1954) that show Ca ranging from 3.2 percent to as high as 30 percent. Magnesium in the same levels ranges from .3 to .7 percent. Total Fe is generally 1-3 percent but is as high as 15.63 percent at the base of the sediment column. Total P is less than .1 percent except at the base of the column, where it rises to .26 percent. Swain suggests that the phosphate at this level probably occurs as vivianite $[Fe_3(PO_4)_2 \cdot 8H_2O]$ or "similar bog phosphate". Roepke (1959) reports iron concentrations in deposits of Misswa Lake, Minnesota that range from .15 to 5.64 percent.

Wright (1974) studied the sediment chemistry of three lakes (Meander, Dogfish, and Lamb) in northeastern Minnesota. He reports phosphorus concentrations of .15-.29 percent for the upper 20-30 cm of sediment. Lamb Lake showed the highest values of P. Calcium concentrations were .3 to .4 percent in Meander and Dogfish lakes but .6-.8 percent in Lamb Lake. Magnesium values were generally .3-.5 percent.

The three lakes studied by Wright are in an isolated wilderness area and thus have been little impacted by man's activities. Another lake in the area (Shagawa) has been studied by Bradbury and Waddington (1973). Shagawa Lake has been heavily impacted by sewage effluents from the nearby town of Ely, which served as an early center for iron-mining activities. The lake is considered to be culturally eutrophic and has phosphorus concentrations approaching .5 percent in the surface sediments. Iron (presumably reaching the lake as a result of mining activities) has maximum values of 10-12 percent near the surface. Pre-settlement iron values are 4-5 percent and phosphorus values are generally less than .2 percent.

The elemental concentrations reported for Myrtle Lake are within the range reported above for other lakes. Because the Myrtle and Squaw Lake sediments were analyzed using the same procedures, it would appear that the analytical techniques are generally satisfactory--at least for "typical" sediments. Two recent studies may explain the extraordinarily high values for P, Fe, and Mn in Squaw Lake.

Anthony (1976) studied the elemental composition of the sediments of Lake of the Clouds in northeastern Minnesota, and attempted to identify the processes causing the formation of sediment bands that have been described by Swain (1974). Anthony analyzed light and dark layers by electron microprobe and wet chemical analysis. He found that "in the dark layers the iron content is generally less than 10 percent, and in the more distinct light layers it exceeds 20 percent at many points." Anthony goes on to state that "wet-chemical analyses show dry weight concentrations of 25.7 percent Fe and 1.15 percent Mn in the aggregate sample dissected from the light layers and 8.3 percent Fe and 0.52 percent Mn in the dark layers." He estimated the distinctness of laminations and compared these estimates with Fe:Mn ratios in the core. Laminations were most distinct where ratios were approximately 10. Distinctness decreased as ratios rose above 15.

Anthony's study included an analysis of the limnology of Lake of the Clouds, and he concludes that the lake (which has a maximum depth of 31 m and is only 12 ha in area) develops a monimolimnion in its deepest waters. This layer is only 2 m thick and is extremely rich in Fe^{++} (as much as 620 ppm). The monimolimnium is partially oxygenated during fall and spring overturn, and the light-colored portion of the couplet (lamina) is formed at this time as a result of the precipitation of iron oxides. The darker layers form from organic remains that settle out during the summer.

The explanation set forth by Anthony for the formation of sediment bands in Lake of the Clouds may apply to Squaw Lake. The lakes are similar in that both are situated on topographic highs (and hence are isolated to some degree from regional groundwater), contain brown low-alkalinity water, and are quite deep. Limnological data will be discussed later, but, like Lake of the Clouds, Squaw Lake probably develops a monimolimnion. Anthony reports values for Fe and Mn that are even higher than those reported here for Squaw Lake, although it should be noted that Anthony was able to isolate light from dark sediments for analysis. The ratios of Fe:Mn are generally higher in Squaw Lake sediments. Only rarely do they fall below 13-14 and never drop below 11.3. Typically they are greater than 15. These high ratios could explain why the laminations are not distinct in much of the Squaw Lake core.

The results of a second study, now being completed by John Miller--a University of Minnesota graduate student, may explain the high phosphorus concentrations in Squaw Lake's sediments. Miller studied the formation of vivianite crystals in Lake of the Clouds' sediments and has refined Anthony's hypothesis. Apparently Fe becomes so concentrated in the monimolimnion that vivianite is precipitated directly from the water. Ferric phosphate that precipitates from the bulk of the hypolimnion during periods of lake turnover resolubilizes when it enters the continuously deoxygenated waters in the deep hole in Lake of the Clouds. It seems likely that the same process occurs in the 24 m hole in Squaw Lake. Miller has unpublished data that show that phosphorus concentrations in Lake of the Clouds' sediments reach .5-1.5 percent. These values are comparable to those for Squaw Lake's sediments. Oxidized vivianite crystals were readily apparent after the unfrozen Squaw Lake core had been exposed to the air for a few hours.

It is at first perhaps somewhat surprising that Myrtle Lake does not also have iron-rich laminated sediments. The lake is meromictic, and much of the water column is deoxygenated most of the year. Miller has suggested, however, that large amounts of humic substances may interfere with the vivianite precipitation process by complexing Fe. Myrtle Lake's waters are highly colored by humic acids, as evidenced by low Secchi disk readings during the entire year. Even if laminae are formed in Myrtle Lake, sediment mixing may destroy the stratigraphy. The sediments contain large numbers of Chaoborus (phantom midge) larvae, and their activity could result in extensive bioturbation. Further evidence for the mixing of Myrtle Lake sediments will be discussed in the following section.

b. Pollen.

1.) Regional setting. Pollen diagrams have been published for several lakes and bogs in the Itasca region. McAndrews (1966) obtained cores from a transect of small ponds running from Cindy Pond, a few kilometers east of Itasca State Park, to Thompson Pond situated in the prairie to the west. Bog D Pond is one of the transect sites and is located within the boundaries of the park. It is approximately 10 km SE of Squaw Lake in an area that has not been heavily logged. A C-14 date of lake sediments at the base of the Bog D column provides a 11000 B.P. date for the initiation of sediment accumulation. McAndrews uses this date to establish the beginning of revegetation in the region following the retreat of the Wisconsin ice sheets. His chronology shows that late-glacial spruce forests were rapidly replaced by forests dominated by Pinus (presumably red or jack pine) and Pteridium. Between 3930 and 8560 B.P., Quercus and prairie herbs (including Artemisia, Ambrosia, and Chenopodiineae) dominate the profile. This assemblage has been correlated with the hypsithermal--a period of warmer and drier climate. About 3930 B.P. the climate apparently cooled and became more moist, as evidenced by a reappearance of Pinus. At this time, however, Pinus strobus pollen dominates the assemblage. About 1000 B.P. Pinus banksiana and/or P. resinosa (the pollen of the two species are indistinguishable) replaced P. strobus. McAndrews cites this as evidence for a further cooling and/or drying of the regional climate. Near the surface of the core McAndrews identified the effects of European man's settlement in the region. Percentages of Pinus pollen fall and Ambrosia pollen percentages rise from about 2.5 percent to nearly 10 percent.

McAndrews' vegetation sequence has been verified by Janssen (1967), who presents a pollen diagram for Stevens Pond (3.2 km NE of Squaw Lake), and by Stark (1976), who presents diagrams for Elk Lake (5 km SE of Squaw Lake). Shay (1971) obtained a C-14 date from the basal sediments of the Nicollet Valley (4.5 km SE of Squaw Lake). His date of 9500 B.P. for the initiation of revegetation has been accepted by Stark (1976) as being more accurate than McAndrews', because the Nicollet Creek date is based on wood rather than on calcareous lake sediments, which may contain carbon derived from limestone.

Janssen (1967) sampled the surface sediments of Stevens Pond more intensively than did McAndrews at Bog D. The Stevens Pond site is in an area cleared during the early 20th Century, and the pollen profile shows that Ambrosia percentages rose at first gradually from about 2 percent to 5 percent and then sharply to about 15 percent. At the same time percentages of total Pinus fell from about 75 percent to 60 percent. Janssen assumes a date of 78 B.P. for the abrupt rise in <u>Ambrosia</u> pollen. The rise occurs simultaneously with the initial occurrence of agricultural herbs and grasses and presumably correlates with the settlement of the area by European man.

2.) Squaw Lake. The percentage diagram for Squaw Lake, with all taxa represented, is found in Figure 9. Profiles for selected important taxa are presented in Figure 10. Raw pollen counts for Squaw Lake are in Appendix C. I attempted to identify at least 500 fossil pollen and spores at each level. In some levels, especially those with white bands, pollen was sparse, however, and only about 300 grains were counted. Pollen concentrations average about 125,000 grains/cc in the uppermost 17 cm of sediment, except near the sediment-water interface, where concentrations are about 75,000 grains/cc. Below 17 cm concentrations generally exceed 150,000 grains/cc, and in the interval 40-50 cm they typically exceed 300,000 grains/cc. Preservation of fossil grains is generally quite good except in the sediment bands. In all cases, however, preservation is sufficient to allow the identification of most grains. All levels between 0 and 22 cm were counted, and an additional ten levels were sampled at irregular intervals between 22.5 and 50 cm. One sample was counted at 65 cm--the base of the unfrozen core.

Below 4.5 cm <u>Pinus</u> pollen dominates the profile with values that usually exceed 50 percent. Above 4.5 cm <u>Pinus</u> drops to a low of 30 percent at the surface, and <u>Ambrosia</u> rises from 2.5 percent to values consistently exceeding 8-10 percent. The lower zone correlates with the <u>Pinus strobus</u> zones identified by McAndrews (Zone 5) at Bog D

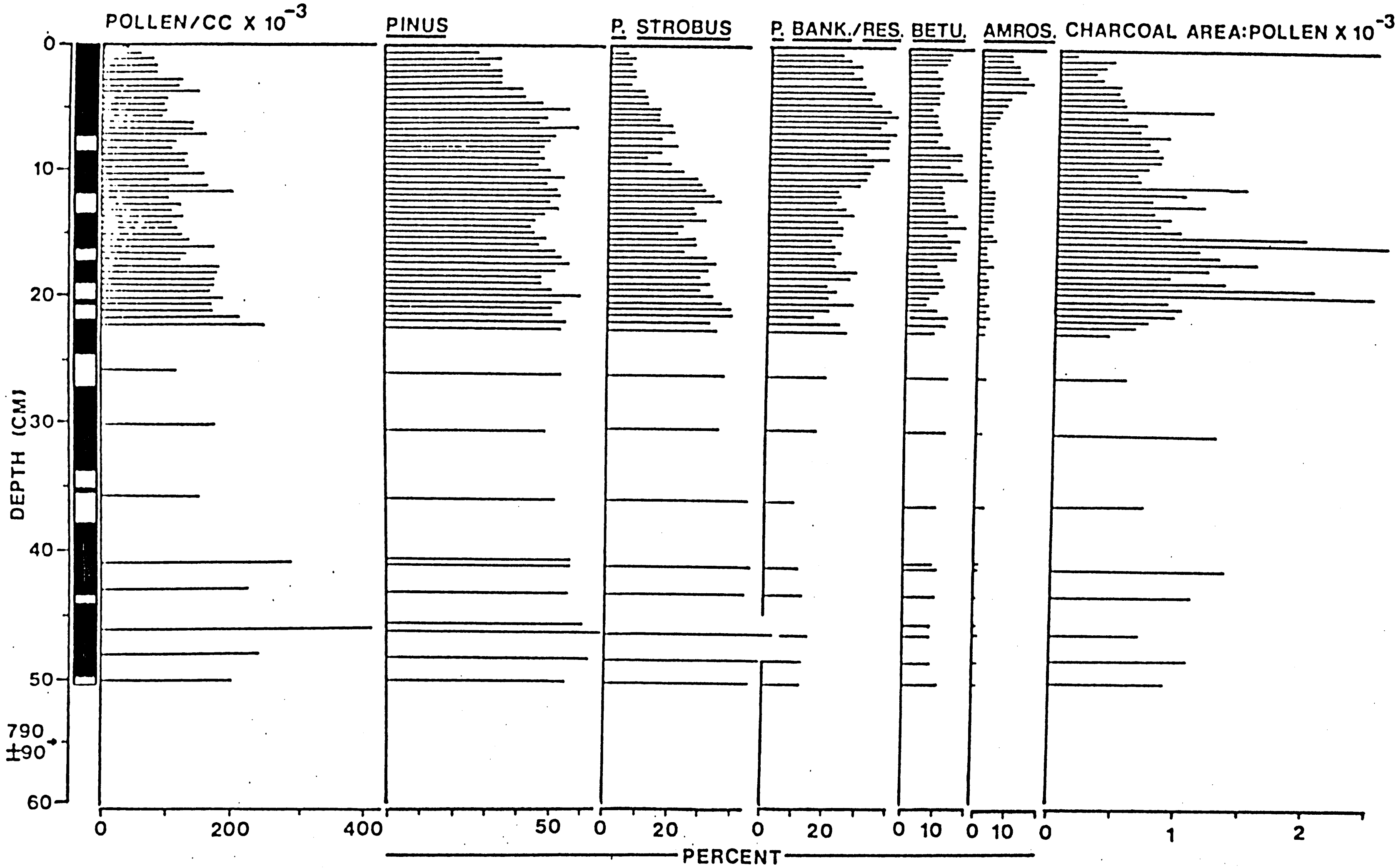


Figure 10. Selected profiles for pollen and charcoal in Squaw Lake sediments.

and Janssen (Zone 4) at Stevens Pond. Below 4.5 cm in Squaw Lake values for total Pinus are about the same as at Bog D and are 10-15 percent lower than at Stevens Pond. Janssen (1967) observes the discrepancy in Pinus values between Stevens Pond and Bog D and suggests that the values at Bog D may be diluted by regional pollen because Bog D has a larger deposition basin than Stevens Pond. This argument would apply to Squaw Lake also.

Both Janssen and McAndrews recognize an upper Pinus banksiana/resinosa subzone where these species appear to replace P. strobus as the dominant pine. Janssen sets the subzone boundary at a point where the ratio of Haploxylon to Diploxylon pine drops below .20. McAndrews sets his subzone boundary at the point where Diploxylon pine values rise above 25 percent of the determinable pine grains. At Squaw Lake the percentage of Pinus strobus declines gradually from values that generally exceed 40 percent of total pollen below 32 cm to values of 20-30 percent between 10 and 32 cm. At 10 cm, however, Pinus strobus values drop sharply (from 28 percent to as low as 10 percent at 8.0 cm). While Pinus strobus percentages are falling, P. resinosa/banksiana values gradually rise from <10 percent to about 20 percent at 10 cm. Between 10 cm and 4.5 cm they rapidly rise to values exceeding 40 percent. The ratio of Diploxylon to total pine pollen first exceeds .25 at about 32 cm, and this can be considered the subzone boundary according to McAndrews' criteria. A more detailed discussion of possible mechanisms contributing to the replacement of Haploxylon by Diploxylon pine is presented in the following chapter.

The decline in pine percentages and coincident rise in _Ambrosia_ at 4.5 cm are clearly associated with settlement of the region. This "culture horizon" has been recognized in pollen diagrams throughout northeastern North America. Its precise dating varies with the locale, and in the Itasca area it was originally set at about 1900 by Janssen (1967). I was interested in a more precise date, however, since the stratigraphy of both pollen and charcoal in Squaw Lake shows sharp changes between levels. Careful examination of the Squaw Lake pollen profile shows that percentages of _Ambrosia_ rise from 1.2 percent at 63 mm to 3.6 percent at 58 mm. They remain between 3 and 5 percent until, at 43 mm, they begin a rapid rise (to a maximum of 16.5 percent at 23 mm). At 43 mm total pine percentages first begin to fall. This stratigraphy suggests that the initial rise in _Ambrosia_ predates by 1.5 cm the initiation of logging at Squaw Lake in 1905. I have therefore dated the culture horizon at Squaw Lake at approximately 1890--ten years earlier than the inferred date of Janssen (1967). The 1890 date has been substantiated by Foster (1976) who studied the annually laminated sediments of Lower LaSalle Lake located 15 km NE of Squaw Lake. Foster was able to sample 2 yr increments of sediment and thus provides a very precise date for the initiation of the _Ambrosia_ rise. He observed little separation between the rise in _Ambrosia_ and the decline in pine, but the watershed of Lower LaSalle Lake was logged 6-7 years earlier than that of Squaw Lake (Vandersluis 1974). The 1890 date for the _Ambrosia_ rise appears to be a regional event that can in some instances, such as Squaw Lake, be separated from local disturbance.

A date of 790±90 C-14 years B.P. (1973) was obtained for the interval 50-60 cm (I-8533). This date yields an average sediment accumulation rate of .70 mm/yr for the interval 0-55 cm. This is close to the calculated rate of .76 mm/yr that is arrived at by dating the initiation of the *Ambrosia* rise at 88 B.P. The rate based on the *Ambrosia* rise incorporates the effect of less compact sediments near the surface, whereas that based on the C-14 date probably includes increased rates during periods when bands were formed. According to the above calculations, each .5 cm level in Squaw Lake represents an average of 7 years of sediment accumulation. This figure will be used to date stratigraphic events.

The occurrence of a culture horizon at about 5 cm in Squaw Lake represents a very slow sediment accumulation rate for Squaw Lake. Foster (1976) identified the *Ambrosia* rise in Lower LaSalle Lake sediments at a depth of 19.5 cm, and Birks *et al*. (1976) placed the *Ambrosia* rise in Elk Lake at 34 cm. Both of these lakes contain $CaCO_3$ laminations, however, and sedimentation rates could be expected to exceed those at Squaw Lake. Other studies have identified culture horizons in Minnesota lakes at depths of between 20 and 40 cm.

Except for the changes in pine and ragweed pollen already discussed, there are few significant fluctuations in other taxa represented in the Squaw Lake pollen profile. Some peaks in *Betula* and *Pteridium* pollen occur, and these may be related to fire occurrence. There are also changes that appear related to settlement. Pollen of Acer saccharinum, Celtis, Carya, Juglans nigra, J. cinerea, Castanea, and Platanus are conspicuously absent above 5 cm. The occurrence of Morus pollen, on the other hand, is restricted to sediments of the past 100 years. In addition to Ambrosia, culture indicators such as Chenopodiineae-type, Zea mays, and Cruciferae are all more abundant above 5 cm.

Pollen types that have obviously been transported long distances include Tsuga and Sarcobatus. Aquatic pollen types are poorly represented in the Squaw Lake profile, with only Typha occurring in large numbers. Some Typha plants occur along the shore of the lake at present, and grains could have been produced locally or deposited with the regional pollen rain.

3.) Myrtle Lake. A percentage pollen diagram for Myrtle Lake is found in Figure 11. Raw pollen counts are in Appendix D. Only 17 levels in the upper 57 cm of sediment were counted. The stratigraphy of Myrtle Lake sediments is not nearly so well defined as that for Squaw Lake, and events and trends that are readily apparent in the Squaw Lake core are either absent in Myrtle Lake or obscure. Myrtle Lake sediments were sampled at 2.5 cm intervals through 25 cm and at approximately 5 cm intervals between 25 and 57 cm, but this lack of sampling precision cannot completely explain the paucity of information in the pollen profiles.

Some trends are apparent, however, and they provide an interesting contrast with Squaw Lake. Between 57 and 12.4 cm Pinus strobus pollen percentages gradually decrease as P. resinosa/banksiana percentages increase. Although percentages of total Pinus are at about the same level as in Squaw Lake, Pinus resinosa/banksiana percentages consistently exceed those for P. strobus. At 12.4 cm total pine percentages begin to decrease (from 54 percent to 29 percent at the surface) while Ambrosia percentages rise from 3.2 to 6-7 percent. Ambrosia percentages never exceed 10 percent, and this may reflect the fact that much of the area within a few hundred meters of the lake was not logged. Although cut stumps occur on the NE shore of the lake, all of the land to the SW was left uncut, and lands to the north of the lake were occupied by a jack pine stand that originated in the early 1890's. Betula pollen reaches 20 percent at the surface of the Myrtle Lake sediment. This value is 7 percent higher than at Squaw Lake, and, although birch is common on the shores of both lakes, the higher percentage at Myrtle Lake perhaps reflects the greater contribution of locally produced pollen to the total pollen rain. Janssen (1967) illustrates the fact that the pollen content of small basins is more affected by local vegetation, whereas large basins receive a greater proportion of their pollen from regional sources. Local pollen may also account for the generally higher percentages of Pinus resinosa/banksiana at Myrtle Lake. It can reasonably be assumed that the 80-year-old jack pine around the lake in 1973 were preceded by similar stands of jack pine.

Other evidence for the influence of local pollen at Myrtle Lake includes the somewhat higher values for Cyperaceae, Gramineae, and aquatic pollen. The lake is bordered on two sides by floating vegetation mat and probably has a littoral area that is larger relative to its total area than does Squaw Lake. An interesting but unexplained feature of the aquatic pollen sum is the abundance of *Nymphaea* pollen below 10 cm. Pollen grains of this taxon are completely lacking above 10 cm.

The profiles from Myrtle Lake generally appear to reflect greater post-depositional mixing than do those from Squaw Lake. Evidence of *Chaoborus* larvae in the sediments has already been mentioned, but there are other indications that mixing has significantly disrupted the stratigraphy. A single grain of *Zea mays* pollen, for example, was found at 40 cm in the sediments--nearly 30 cm below the settlement horizon. *Zea* pollen is rare in sediments except when the plant is cultivated near the deposition basin. Single grains occur at the surface of the Myrtle Lake sediments and near the settlement horizon in Squaw Lake. Janssen (1967) found *Zea* pollen only in sediments deposited since settlement in Stevens Pond, and it seems highly unlikely that the *Zea* grain found at 40 cm in Myrtle Lake was produced prior to settlement. This grain probably was transported 25-30 cm in the sediments following deposition. That pollen can be transported large vertical distances in sediments has been demonstrated empirically by Davis (1974).

C. Charcoal. For many years paleoecologists and archeologists have used sedimentary charcoal as an indicator of fire. Most early studies involved the simple recording of the presence of burned fragments, usually in peat (Woodhead 1924, Iversen 1934) or at archeological sites (Salisbury and Jane 1940). Iversen (1941) first published a pollen diagram with an accompanying profile for charcoal. Since that time several charcoal profiles have been published for basins in a number of geographic locations (Iversen 1964, Goulden 1966, Davis 1967, Fredskild 1967). A variety of techniques were used by these researchers, and quantitative comparisons between studies are generally not possible. Only recently, with the publishing of several charcoal profiles by Minnesota researchers, has some standardization been introduced. Waddington (1969), Bradbury and Waddington (1973), Swain (1974), Amundsen (1974), and Foster (1976) all use area estimate methods similar to the one I have described. Area estimates have also been used by Brugam (1975) in Connecticut and by Cwynar (1978) in Ontario. All of these studies have been discussed in detail in another paper (Patterson 1976).

1.) Squaw Lake. The occurrence of fire in the Squaw Lake watershed is established with evidence from land based studies. The objectives of the sedimentary charcoal analysis are: 1) to determine if evidence of fire could be found in the sediments; and 2) to try to relate the evidence of fire to other sediment characteristics. The discussion in this section is limited to the first objective, with the discussion of the second appearing in Chapter VI.

Six methods were used to express charcoal: area and number of fragments per cc wet sediment; the ratio of area and number of fragments to pollen; and area and number of fragments per gm of sediment (o.d.w.). Profiles for each of these are presented in Figure 12. A detailed statistical analysis of the charcoal data was conducted with the assistance of R. Nordheim, Dept. Applied Statistics, U. of Minnesota. We concluded that the ratio of charcoal area to pollen is the most informative means of expressing the data, and I have included the profile for these ratios in Figure 10. A detailed account of the statistical study will be published separately.

All six charcoal profiles show distinct peaks in charcoal concentrations. Many of these peaks coincide from one profile to the next, although differences do occur. Above about 16 cm there is a close correspondence between the charcoal peaks and inferred dates of fires known to have occurred in the Squaw Lake watershed. Peaks shown on Figure 10 are dated as follows: 47 mm, 1902-1909; 67 mm, 1873-1880; 83 mm, 1852-1859; 108 mm, 1816-1823; 123 mm, 1794-1802; and 153 mm, 1752-1759. These dates are all within ±1 level of known fires. Below 16 cm the peak at 17 cm is difficult to interpret. Although Frissell indicates that a fire burned east of Squaw Lake in 1727, I am not confident that the chronology I propose is accurate to within ±10 years at this depth in the core. The white sediment bands at about 8, 13, and 17 cm may represent periods of rapid sediment accumulation, and dates below the bands may appear to be too old unless sediment accumulation for the intervening levels slowed to less than .7 mm per year. This probably did occur over the length of the core, but in the interval between 18 and 22 cm, where several bands occur, calculated dates are probably too old.

Several characteristics of the profile are puzzling. The peak associated with the 1864 fire is not so large as some of the other peaks. It also appears spread out more than, for example, the peak at 15 cm. A number of factors may contribute to varying charcoal concentrations. Little is known about how charcoal is transported to lakes, but the importance of hydrologic relative to aeolian transport could be a significant factor affecting sediment concentrations. This is especially true for basins like Squaw Lake that receive large amounts of streamflow. If hydrologic transport is important to Squaw Lake, fires burning to the east and north probably contribute less charcoal than fires burning to the south and west.

Redeposition and sediment mixing must also be considered. Both processes are known to affect the distribution of pollen in sediments (Davis 1967, Davis 1972). In Squaw Lake sediments the upper 3-4 cm contain as much charcoal (on an o.d.w. basis) as levels deeper in the core. This indicates that mixing and/or redeposition have occurred in recent years.

The correlation of charcoal peaks with known fires is made difficult by the fact that many fires occurred in the Itasca area, and, depending upon one's assumptions, it is possible to relate almost all peaks on the six different profiles to fires that occurred within ±10-15 years of a given peak. Nevertheless, high charcoal concentrations at 4.5, 8.0, and 10.5-12.5 cm correspond with fires known to have occurred at Squaw Lake about 1910, 1864, and 1800-1820, respectively. The first two dates are found by Foster (1976) to correspond to charcoal peaks in Lower LaSalle Lake. Foster sampled Lower LaSalle's laminated sediments at two-year intervals and has constructed the most precise charcoal profile available. In addition to the dates mentioned above he has identified peaks that probably correspond to fires occurring in 1874, 1880, 1894, 1908, and 1916. Foster sampled a second core from Lower LaSalle at 5-year intervals and found that the charcoal stratigraphy was less clear. His results demonstrate that sampling charcoal from levels representing more than a few years may obscure peaks that are confined to very narrow sediment layers. The sampling of levels that represent more than 2-3 years could significantly decrease precision in lakes where little sediment mixing occurs. At Squaw Lake, the .5 cm sampling interval may have obscured some charcoal peaks where more than 7 years were represented. On the other hand, peaks near sediment bands may be greater because fewer years are represented in each interval.

As with other parameters, the charcoal content of sediments between 40 and 50 cm differs substantially from that of levels higher in the core. On a volumetric basis (profiles I and II, Figure 12) concentrations appear quite high. Pollen concentrations in this interval are also high, however, and expressing charcoal relative to pollen (profiles II and IV) results in some of the lowest concentrations in the core. Three factors, probably working in concert, may have accounted for the unusual pollen and charcoal concentrations between 560 and 700 B.P. First, it is likely that pollen production was high. Pollen of <u>Pinus strobus</u>, an abundant producer, dominates the profile, and local populations may have contributed much pollen. It seems likely, in addition, that sediment accumulation rates were less during this period. The sediments contain more organic matter than do those in the upper portion of the core; perhaps reflecting reduced inputs of allochthonous inorganic particulate matter. Finally, it is possible that fires were less frequent. Fewer fires could result in denser stands of pine and less runoff to the lake.

2.) Myrtle Lake. Charcoal profiles for Myrtle Lake appear in Figure 11. Sampling was accomplished at such broad intervals (about every 20 years in the upper 25 cm) that there is no possibility of recognizing peaks associated with specific fires. Values gradually decrease toward the sediment-water interface, probably as a result of declining fire frequency and reduced sediment compaction. Concentrations of charcoal in Myrtle Lake's sediments are comparable to those in Squaw Lake's sediments. Because sediments appear to be accumulating twice as fast in Myrtle Lake compared to Squaw Lake, the influx of charcoal is apparently twice as great at Myrtle Lake. Increased influx may result from decreased wind speeds across the small basin, while failure of much of the water column to turn over may lower losses of resuspended pollen and charcoal in the spring and fall.

B. Neoecology

Much of the neoecological sampling was done to establish initial conditions for a number of terrestrial and aquatic parameters. The pine restoration program west of Squaw Lake should continue over a period of years, and only the early effects of logging and burning are documented in this study. Because the data are largely descriptive, a long discussion for each parameter is not warranted. It is important, however, that the data are recorded and discussed in a way that will allow others to duplicate the sampling procedure. A great deal of effort went into collecting data that will be meaningful only when compared with similar data collected in the future.

1. Vegetation.

a. Plot descriptions. Twenty six .1 acre (.0405 ha) plots were sampled at least once in 1973, 1974, and 1975. Sampling in 1975 was limited to plots that were completely burned. Of plots that were clearcut in 1974, two jack pine (J and W) and two aspen (V and P) plots were chosen. In addition two new plots (I and F) were established near the shore of Squaw Lake. These were selected because they represent unlogged stands of aspen (F) and birch (I), the forest floors of which were completely burned. They provide a contrast with the clearcut and burned plots.

As a result of the sampling during the three summers, four plots (J, P, V, and W) were sampled three times and four were sampled once (F, I, R3, and R4). The remaining 18 plots were sampled twice. Of the plots west of Squaw Lake, only plot C was not logged at least partially, and any differences between 1973 and 1974 data for this plot represent normal year-to-year variation. Plot Z was sampled in the fall of 1976 for aspen understory data only. In 1975, an effort was made to retard the growth of aspen on this site. A bulldozer with its blade lifted about one foot (.3 m) above the ground was driven back and forth across the area in late June. The effect of this operation was to bend over the 4.5-6 m tall aspen saplings and peel the bark from their stems. The following October the area was burned, and the 1976 sampling was done to determine the effect of this treatment on aspen suckering.

The location of all plots is shown on Figure 13. Plot descriptions are summarized in Appendix E. Plot centers are marked by a ½" (1.3 cm) galvanized steel pipe, and an effort will be made to maintain these centers so that the plots can be resampled in the future. Plots that contain pine stumps from early logging are: A, C, D, E, F, G, I, K, L, M, R3, and Z. Except for plot Y, all plots that show no evidence of logging are on the south and west side of the study area. Much of this land contained jack pine dating to the early 1890's, and early logging probably did not significantly alter these stands. Plot R4 is north of the study area, but until 1966 it contained mature jack pine that had not previously been logged. Following the logging in 1966, however, the area was heavily disturbed. Apparently it was bulldozed in an effort to eliminate brush competition. Red pine seedlings were then planted mechanically.

Only plots P, H, and S showed no evidence of past fires (burned stumps, fire-scarred trees or charcoal in the forest floor). Recent beaver activity was observed at plots A, J, and especially P where several trees were felled about 1960. In 1973, deer browse activity appeared to be greatest on plots J, T, and Z. After logging, activity in the entire area increased as deer fed on slash and later on young aspen suckers.

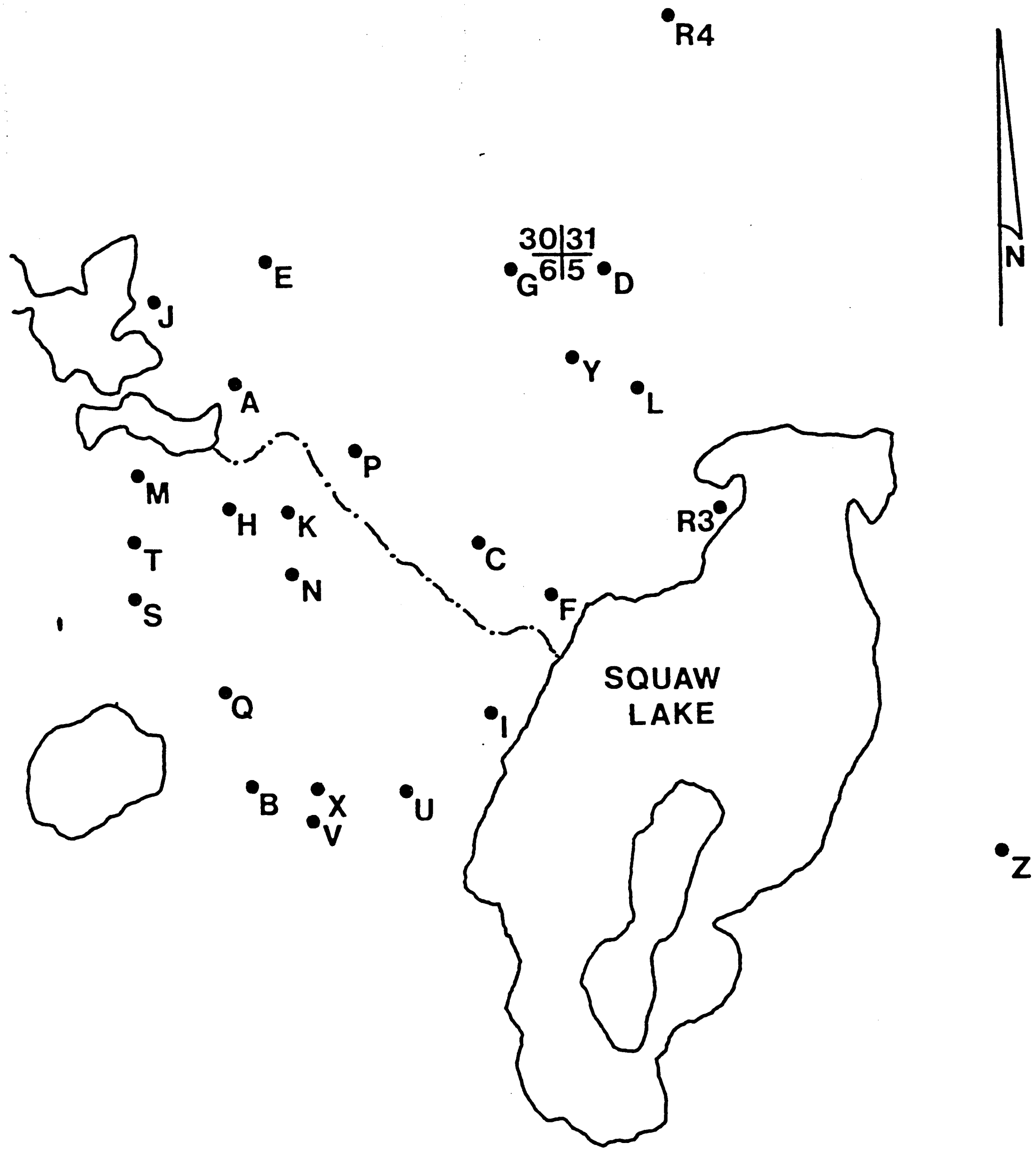


Figure 13. Map of plots sampled for vegetation.

b. Overstory. Age, height, and volume data for selected tree species are summarized in Table 6. Volume estimates were calculated from the stand-volume equation of Buckman (1961). Site indexes were taken from curves in the USFS Region Nine Timber Management Field Book and were determined only where stand ages were reasonably precise. For most plots, site index for aspen was good to very good (greater than 60). Alban (1976) devised a method for predicting potential red pine site index using aspen site index. Generally, red pine will not grow so fast as aspen on sites where the aspen site index exceeds 50. It seems likely that the sites west of Squaw Lake that have the highest aspen site indexes will probably be the most difficult to convert to pine.

Volume estimates for aspen average 17.8 cords/acre on the 14 plots where aspen is the dominant species. Volume and site index estimates are generally lower for birch than aspen. Jack pine site indexes are comparable to those for aspen, but volumes are greater, in part because the stands are 20-30 years older. The volume estimate for red pine at plot R3 is the highest of the 26 plots. Basal area estimates for red pine on this plot exceed 200 ft^2/acre.

Data from the 1973 survey of stumps on the .1 acre plots are summarized in Appendix F. Most plots had only a few large pine stumps or none at all. Plots C, G, and R3, however, all had at least 7 cut pine stumps. These stands undoubtedly supported the largest volumes of pine prior to early logging. Following logging, plot R3 regenerated to pine, while plots C and G regenerated to

Table 6. Summary of tree data for vegetation plots.

Area	Species	1973* Age	Core Ht.	Probable Stand Origin	Median Height	Site Index	Volume (Cords)
A	*Populus tremuloides*	46/50/49/46/ 53/48/48	dbh	1922-1924	77	78	35.0
B	*Betula papyrifera*	47/45/48/48/ 43/49/48	dbh	1921-1925	52	52	9.6
C	*Betula papyrifera*	61/51/54/55/ 46/51/55	dbh	1915-1919	52	48	18.5
D	*Populus tremuloides*	54/51/49/47/ 51/51/51	dbh	1918-1924	64	63	20.6
E	*Populus tremuloides*	42/42/42/44/ 40/30/46	dbh	1927-1930	58	62	15.76
G	*Betula papyrifera*	43/50/52/48/ 43/47/47	dbh	1919-1924	62	62	17.8
H	*Populus tremuloides*	58/46	dbh	1914-1926	69	--	11.9
J	*Pinus banksiana*	77/72/77/75/ 77/73	12"	1893-1895	79	65	45.6
K	*Populus tremuloides*	56/55	dbh	1918	63	60	7.7
L	*Betula papyrifera*	57/54/55/58/ 58/58/55	dbh	1912-1916	60	54	8.1
M	*Populus tremuloides*	47/47/50/47/ 48/53	dbh	1919-1924	63	63	13.5

Table 6. Continued.

Area	Species	1973* Age	Core Ht.	Probable Stand Origin	Median Height	Site Index	Volume (Cords)
N	*Populus tremuloides*	56/62	dbh	1910-1916	75	--	19.7
P	*Populus tremuloides*	57	dbh	1915	69	--	14.6
Q	*Populus tremuloides*	50/48/49/60/48/48/53	dbh	1919-1922	75	75	26.4
R3	*Pinus resinosa*	52/52/52/52/53/54/52	12"	1915-1917	57	52	50.7
S	*Populus tremuloides*	46/54/47/43/45/46/44	dbh	1925-1929	63	66	19.8
T	*Betula papyrifera*	40/40/43/46/52/39	dbh	1927-1930	56	60	8.2
U	*Populus tremuloides*	39/44	dbh	1928-1933	47	63	6.3
V	*Populus tremuloides*	46/46/46/45/46/46/46	dbh	1926	59	61	25.9
W	*Pinus banksiana*	77/75/76/75/76/79	12"	1893-1896	65	55	35.1
X	*Populus tremuloides*	50/50/49/52/58	dbh	1920-1922	66	66	18.9

Table 6. Continued.

Area	Species	1973* Age	Core Ht.	Probable Stand Origin	Median Height	Site Index	
Y	Populus tremuloides	58/52/58/50/ 56/59	dbh	1912-1920	57	55	13.9
Z	Populus tremuloides		-	1968	20.3		0.4
R4	Pinus resinosa		-	1966	10.3		0.4

*Numbers underlined indicate median

birch. Stumps of small willow trees (probably Salix humilis) were common on several plots (E, P, S, T, and U). Salix apparently regenerated well following the logging and burning 60 years ago, and data from the 1974 and 1975 understory plots indicate that Salix sprouted vigorously following the recent disturbances. Both the Squaw Lake and Myrtle Lake pollen profiles show Salix pollen to be most abundant just above the start of the Ambrosia rise. Since most of the 1973 plots contained only overmature Salix, evidence indicates that disturbance frequencies of less than 60 years are needed to maintain vigorous stands of Salix.

The degree to which individual plots were affected by logging can be seen by comparing the 1973 and 1974 basal area data (Table 7). Plots that were clearcut or nearly so include: A, E, G, J, Q, S, V, and W. In addition, all jack pine were removed from plot B and all aspen were removed from plots K, L, and N. Aspen basal area was reduced by at least 80 percent on plots D, H, P, U, X, and Y.

The vegetation of the study area was classified with plot data for species composition and tree density. The optimal agglomeration-polythetic clustering method of Orloci (1967) was used to mechanically group plots. The clustering routine (OPTAGG5) was written by E.J. Cushing and produces a hierarchial dendrogram in which the classes at any one level are subclasses of higher levels. Two similarity indices were used to generate individual dendrograms--absolute and standardized Euclidian distance. Both evaluate the distance between plots in an n-dimensional hyperspace where n equals the total number

Table 7. Effect of logging on tree basal areas.

Plot	Basal Area (sq ft/acre) 1973	1975	Percent Reduction
A	106.7	0	100
B	97.1	35.2	64
C	99.4	99.4	0
D	102.0	54.1	47
E	68.4	3.6	95
G	91.7	11.2	88
H	58.9	19.5	67
J	136.9	0.2	100
K	86.1	23.7	72
L	120.2	37.9	68
M	74.0	43.7	41
N	94.7	20.9	78
P	64.4	16.5	74
Q	87.6	0	100
S	76.9	0	100
T	61.0	50.5	17
U	55.7	13.8	75
V	101.9	0	100
W	122.9	0	100
X	99.5	17.5	82
Y	88.2	35.5	60

of species (attributes) for all plots (entities). Absolute distances are found by simply computing distances between points. By contrast, standardized distances are obtained by projecting points representing plots onto a unit circle centered on the origin. The standard distances are then taken as the cords between the resulting points on the circle. When absolute distances are used, more emphasis is placed on species abundance than on species composition. The reverse is true for standard distance. For the tree data, stem basal area was used as a quantitative measure of species abundances. Understory and herb data were also clustered with OPTAGG5 using other species abundance measures.

For clusters of overstory vegetation, absolute distance measures gave results that were somewhat easier to interpret--primarily because most of the plots differed more in stem density than in species composition. Two absolute distance dendrograms were produced, one with all plots, the other with only those plots that had not been cut in the previous 1-2 years (1973 plots plus I5, F5, R4, and Z4). The classification scheme presented in Table 8 is based upon the latter dendrogram. Information from a standard distance dendrogram was also incorporated into Table 8. It was necessary to do this because the absolute dendrogram placed plot R4 (sapling red pine) with a group of aspen plots having generally low basal areas rather than with plot R3 (pole-sized red pine). Dendrograms with all plots did not alter the classification scheme in Table 8 significantly but did add an additional group containing 11

Table 8. Squaw Lake cover type classification based upon tree species basal area date.

Group	Description	Plots
I.	*Populus tremuloides* dominant	
	a.) *P. tremuloides* > 63 sq ft/acre	A3, V3, D3, E3, Q3, S3, X3
	b.) *P. tremuloides* b.a. < 49 sq ft/acre	H3, Z4, P3, U3, K3
II.	*Populus grandidenta* dominant	F5
III.	*Betula papyrifera* dominant	B3, B3
	a.) *B. papyrifera* b.a. < 42 sq ft/acre some *Pinus banksiana* present	B3, T3
	b.) *B. papyrifera* b.a. > 66 sq ft/acre	C3, G3, I5
IV.	Mixed *Populus tremuloides*-*Betala papyrifera*	L3, M3, N3, Y3
V.	*Pinus banksiana*	J3, W3
VI.	*Pinus resinosa*	R3, R4

plots sampled in 1974 (D, L, N, Y, E, P, H, G, U, X, K). All these plots had very low total basal areas. Plots B4, M4, and T4 were partially logged, but, as has been mentioned, most birch were left standing, and these plots were clustered separately with plots B3 and T3. The types listed in Table 8 represent a refinement of Meyer's 1966 aerial photo interpretation of the park's vegetation, in that they allow for the differentiation of Meyer's aspen-birch into three distinct units; aspen, mixed aspen-birch, and birch. The groups do not, however, represent discrete vegetation communities. Variations within the groups indicate that transitions between groups occur (e.g. plot D has a high aspen basal area but is like L and Y in that it has significant amounts of birch and red oak).

c. Understory. The effort to restore pine at Squaw Lake will be successful only to the extent that regrowth of deciduous species is controlled. Prior to logging, hazel (Corylus cornuta Marsh.) dominated the understory of most plots. Hazel and especially aspen sprouted vigorously following logging and burning on most plots. The analysis discussed here emphasizes post-treatment changes in frequency, density, and basal area. Differences in understory between plots of differing cover types are also discussed.

1.) Cluster analysis. Plots were grouped using absolute distance. Separate dendrograms were generated for the three parameters mentioned above. The reordered input matrix values for selected species, with plots ranked as they are on the dendrograms, appear in Tables 9, 10, and 11. Clustering generally separated

Table 9. Reordered input matrix for shrub frequency dendrogram.

Plot	Diervilla lonicera	Corylus cornuta	Viburnum rafinesquianum	Populus tremuloides		
A3	20	66	40	6		
M3	13	86	26	20		
V3	13	59	59	13		
J3	26	73	40	13		
T3	40	66	40	0		
T4	6	86	20	0	IA	
E3	53	66	32	13		
W3	59	80	46	6		
B3	20	80	26	40		
B4	33	46	53	33		
R3	26	26	0	0		
Q3	20	66	46	13		
J4	33	73	66	13		
X3	20	53	80	13		
J5	46	93	100	6		
F5	33	93	73	26	IB	I
I5	20	86	73	59		
M4	13	100	59	53		
W4	59	86	53	6		
R4	46	26	73	13		
C3	20	59	26	40		
C4	26	40	33	46		
L3	26	26	33	20		
K3	20	40	40	33	IC	
S3	13	59	33	46		
Y3	20	33	20	20		
P3	6	40	20	53		
U3	20	26	73	40		
D3	6	80	0	20		
N3	13	93	0	33	ID	
G3	13	80	6	6		
H3	6	93	0	40		
A4	26	80	26	13		
G4	20	93	20	86		
H4	20	66	13	80	IIA	
D4	46	93	6	66		
L4	26	46	40	80		
E4	59	59	73	93		
Q4	40	59	33	80		
Y4	40	46	60	100		
Z4	59	40	66	73		
K4	33	46	73	73		II
S4	13	40	59	86		
N4	6	66	66	93	IIB	
P4	53	26	73	100		
U4	26	6	86	80		
P5	20	6	93	93		
V4	0	46	80	93		
V5	13	40	93	100		
X4	20	46	80	66		
W5	23	53	100	80		

Table 10. Reordered input matrix for shrub density dendrogram.

Plot	Corylus cornuta	Viburnum rafinesquianum	Populus tremuloides	Betula papyrifera				
A3	6	2	0	0				
K3	5	2	1	0				
C3	5	1	1	0				
D3	6	0	0	0				
Q3	6	1	0	0				
G3	5	0	0	0				
S3	4	0	1	0				
Y3	5	0	0	0				
L3	2	1	1	0				
P3	2	1	1	0		IA1		
R3	1	0	0	0				
U3	3	3	0	0				
X3	4	3	0	0				
C4	3	1	1	0			IA	
X4	5	4	5	0				
Z4	2	5	1	0				
L4	2	1	4	2				
B4	8	3	1	3				
R4	1	3	0	5				
E4	7	3	14	0				
K4	8	4	7	0				
P4	7	2	7	0		IA2		
U4	0	6	9	0				
P5	0	10	10	0				
V5	7	10	24	2				I
B3	12	1	1	0				
I5	14	2	3	1				
T3	12	2	0	0				
W3	12	2	0	0				
T4	13	0	0	2				
V3	15	2	0	0	IB1a			
E3	10	1	0	0		IB1		
J3	10	1	0	0				
H3	9	0	1	0				
N3	8	0	1	0				
J4	11	9	0	0				
M3	19	0	0	0			IB	
M4	18	2	2	3	IB1b			
F5	26	8	1	0				
H4	17	1	13	4				
S4	12	3	14	3				
V4	16	4	9	0	IB2a			
D4	8	0	7	6				
G4	8	1	4	2				
H4	12	0	7	6		IB2		
Q4	14	2	5	9				
W4	13	4	0	5				
Y4	9	1	5	14				
N4	7	2	15	27	IB2b			
J5	28	37	0	0				
W5	22	41	11	0				II

Table 11. Reordered input matrix for shrub basal area dendrogram.

Plot	Corylus cornuta	Populus tremuloides	Subgroup	Group	Cluster
A3	228	0		IA	I
M4	223	14		IA	I
W4	239	7		IA	I
C3	198	8		IA	I
S3	171	8		IA	I
Y3	158	15		IA	I
D3	230	2		IA	I
L3	91	3		IA	I
G3	88	3		IA	I
K3	120	4		IA	I
C4	97	44		IA	I
Q4	91	38		IA	I
U3	135	31		IA	I
B4	147	28		IA	I
J4	121	0		IA	I
P3	92	80		IA	I
L4	34	55		IA	I
Y4	65	83		IA	I
D4	125	66		IA	I
G4	93	86		IA	I
R3	19	0		IA	I
F5	67	5		IA	I
I5	48	0		IA	I
R4	2	62		IA	I
J5	51	1		IA	I
W5	52	40		IA	I
A4	288	196	IB1	IB	I
V4	233	166	IB1	IB	I
H4	190	131	IB1	IB	I
E4	183	221	IB1	IB	I
P4	132	139	IB1	IB	I
K4	178	323	IB2	IB	I
N4	141	372	IB2	IB	I
S4	99	350	IB2	IB	I
V5	9	461	IB2	IB	I
U4	7	208	IB2	IB	I
X4	114	229	IB2	IB	I
Y4	65	83	IB2	IB	I
P5	1	232	IB2	IB	I
B3	303	27		IIA	II
N3	316	3		IIA	II
X3	368	0		IIA	II
T4	340	0		IIA	II
H3	321	2		IIA	II
Q3	262	0		IIA	II
E3	389	12		IIA	II
J3	468	0		IIA	II
M3	428	2		IIA	II
V3	457	6		IIA	II
T3	605	0			II
W3	670	0			II

pre-treatment and post-treatment plots into distinct groups, and an interpretation of each of the dendrograms follows.

a.) Frequency dendrogram. The dendrogram based upon species frequency of occurrence on 15, 1 m^2 subplots can be divided into two major groups. Thirty-two plots (Group I) have aspen frequencies of less than 55 percent, whereas the remaining 19 plots (Group II) all have aspen frequencies of 66 percent or more. Only eight plots in Group I were cut or burned, and, of these, only M4 (which was only partially logged) was not either a burn-only plot or a plot with an original overstory of jack pine or mixed jack pine-birch. Except for Z4, all plots in Group II were recently cut. Of the four sample plots that were cut and burned, only J5 is not in Group II. Plot W5 formerly had a jack pine overstory (as did J5) and was included in Group II only because it contained a large number of aspen seedlings (not suckers). Few aspen seedlings were found on plot J5. This plot was burned in September 1974, whereas W5 was burned in May 1975. I do not know if the lack of aspen seedlings on J5 is related to season of burning. Plot J5 was the only plot where pine seedlings occurred on more than one sub-plot. The 2 ha area that was burned in September 1975 was seeded with 2 lb (5.1 kg) each of red and jack pine in March 1975.

Group I is divided into four subgroups, the first of which (IA) is distinguished by high Corylus frequencies and generally low frequencies of Viburnum. Subgroup IB has high frequencies of both Corylus and Viburnum, whereas subgroup IC is characterized by low to moderate frequencies of Diervilla, Corylus, and Populus. The plots in subgroup ID are unique in that they contain little Viburnum. Little else distinguishes the four subgroups. Of perhaps some significance, however, is the fact that all of the plots that originally contained red or jack pine in the overstory (J, W, X, B, T, R3, and R4) are in subgroups IA and IB. The understory of the unlogged, burn plots (F5 and I5) contrasts sharply with the understory of the aspen plots that were cut before burning (V5 and P5). Burn-only plots have much higher frequencies of hazel but lower frequencies of aspen.

b.) Stem-density dendrogram. Two major groups are identified, the second of which contains only two plots--J5 and W5. These two former jack pine plots contained very high densities of both Corylus and Viburnum. Group I contains the remaining 49 plots and has two subgroups--each with recognizable subsets. Distinguishing features can be seen on Table 10. The groupings of some plots appear to reflect treatment effects. Subsets IA2 and IB2 contain only plots that were logged or logged and burned. Subsets IA1 and IB1 contain all of the untreated plots, but some plots that were treated also fall in these subsets. Only plot X4, however, is unusual in that it is the only plot that had a large amount of aspen cut from it and showed little aspen sprouting.

c.) Basal-area dendrogram. This dendrogram initially separates twelve plots (Group II), all but one of which were uncut. They are characterized by basal areas of Corylus in excess of 3.03 cm^2/m^2. A subgroup (IIB) contains the two jack pine plots. They are characterized by very high basal areas of Corylus (>6.05 cm^2/m^2).

Group I has 39 plots, all with Corylus basal areas ≤2.88 cm^2/m^2. Thirteen treated plots make up subgroup IB. Except for Y4, all have large amounts of Populus. A subset (IB1:A4,V4,H4,E4, and P4) also have high Corylus basal areas. Subgroup IA contains 26 plots, with little Populus and varying amounts of Corylus. Treated and untreated plots are represented, including the jack pine plots that were logged (W4 and J4) or logged and burned (W5 and J5), the two red pine plots (R4 and R3), and the plots that were burned only (F and I). The dendrogram combines plots D3 and L3 in subgroup IA because they have high basal areas of Cornus rugosa (≥1.43 cm^2/m^2).

2.) Species effects. Table 12 gives understory species diversities for each plot before and after treatment. Generally treatments either increased or had little effect on species diversity. There were no instances where species diversity dropped substantially either after logging or burning.

Density and cover (basal area) data for aspen and hazel are summarized in Table 13. The ratio of the variance to the mean is included as a measure of the dispersal (or contagiousness) of stems within the .1 acre plots (Greig-Smith 1964). Where $s^2/\overline{X}$ is approximately equal to one, population elements are considered to be dispersed at random. Ratios less than one indicate a regular distribution (underdispersed), whereas ratios greater than one indicate clumped (overdispersed) populations.

Table 12. Shrub species diversity for all plots, categorized by treatment. (CC=clearcut, PC=partial cut, B=burn)

Plot	Treatment	Year 1973	1974	1975
Group IA				
A	CC	8	10	—
V	CC-B	11	10	9
E	CC	11	14	—
Q	CC	12	12	—
S	CC	7	11	—
X	CC	13	15	—
D	PC	16	21	—
Group IB				
P	CC-B	11	14	13
U	CC	7	12	—
K	CC	12	13	—
H	PC	5	16	—
Z	—	—	12	—
Group II				
F	B	—	—	15
Group III				
B	PC	10	11	—
T	PC	11	12	—
C	—	12	11	—
G	CC	13	16	—
I	B	—	—	17
Group IV				
L	CC	10	11	—
Y	CC	10	15	—
M	PC	11	10	—
N	PC	11	11	—
Group V				
J	CC-B	11	8	12
W	CC-B	8	10	11
Group VI				
R3	—	9	—	—
R4	—	—	16	—

Table 13. Density and basal area summary for aspen and hazel understory data.

	Populus tremuloides									*Corylus cornuta*								
	# stems						cm^2 b.a.			# stems						cm^2 b.a.		
	1973		1974		1975		1973	1974	1975	1973		1974		1975		1973	1974	1975
Plot	$\bar{X}$	$s^2/\bar{X}$	$\bar{X}$	$s^2/\bar{X}$	$\bar{X}$	$s^2/\bar{X}$	$\bar{X}$	$\bar{X}$	$\bar{X}$	$\bar{X}$	$s^2/\bar{X}$	$\bar{X}$	$s^2/\bar{X}$	$\bar{X}$	$s^2/\bar{X}$	$\bar{X}$	$\bar{X}$	$\bar{X}$
A	.2	3.0	12.7	9.1	23.9	3.3	0	2.0		5.8	7.4	16.8	31.4			2.3	2.9	
V	.1	1.2	9.1	4.2			.1	1.7	4.6	15.2	38.8	15.7	34.3	6.8	27.9	4.6	2.3	.1
E	.2	1.6	14.1	9.4			.1	2.2		9.5	7.2	7.4	13.9			3.9	1.8	
Q	.3	1.6	4.8	6.6			0	.4		6.4	10.6	14.3	55.5			2.6	.9	
S	1.1	2.1	13.7	5.9			.1	3.5		3.7	8.4	12.3	42.1			1.7	1.0	
X	.1	1.2	5.3	9.1			0	2.3		4.1	18.0	4.8	17.4			3.7	1.1	
D	.2	.8	7.1	17.4			0	.7		5.9	7.1	8.1	8.8			2.3	1.3	
P	1.4	1.9	6.5	9.1	10.0	5.8	.8	1.4	2.3	2.3	7.6	7.0	35.1	.1	2.7	.9	1.3	0
U	.4	.7	8.5	15.9			.3	2.1		2.8	13.0	.4	6.0			1.4	.1	
K	.9	2.2	7.2	6.4			0	3.2		5.4	38.1	7.7	21.4			1.2	1.8	
H	.7	1.5	6.5	5.3			0	1.3		9.3	9.2	11.7	32.6			3.2	1.9	
Z	-	-	1.3	1.0	5.2	3.9	-	2.5	.7	-	-	1.5	4.4			-	.3	
F	-	-	-	-	.9	5.5	-	-	.05	-	-	-	-	25.6	17.3	-	-	.7
B	.7	1.4	1.3	6.4			.3	.3		11.7	12.0	7.8	22.8			3.0	1.5	
T	0	-	0	-			0	0		11.7	24.8	12.8	12.4			6.1	3.4	
C	.9	2.7	1.4	2.2			.1	.4		5.2	6.7	2.5	7.9			2.0	1.0	
G	.4	1.7	3.9	3.0			0	.9		4.5	5.1	7.5	6.4			.9	.9	
I	-	-	-	-	3.1	3.9	-	-	.1	-	-	-	-	13.7	12.2	-	-	.5
L	.5	3.7	4.4	7.0			0	.6		1.8	7.6	2.1	6.4			.9	.3	
Y	.2	.8	4.6	2.7			.2	.8		4.7	23.9	9.1	39.3			1.6	.7	
M	.3	1.7	1.6	2.9			0	.1		19.4	14.7	17.9	9.0			4.3	2.2	
N	1.0	3.7	15.2	11.1			0	3.7		8.4	10.3	6.9	10.8			3.2	1.4	
J	.2	1.6	.3	1.6	.1	.7	0	0	0	9.5	9.4	11.2	16.4	27.5	47.6	4.7	1.2	.5
W	.1	.7	.3	5.5	10.8	24.3	0	.1	.4	12.3	12.1	13.4	44.2	21.5	46.9	6.7	2.4	.5
R	0	-	.1	1.2			0	0		1.4	7.4	1.1	5.5			.2	0	

Hazel densities averaged 7.05 stems/m^2 on the 23 untreated plots. Maximum densities exceeded 10.0/m^2 on all plots except R3, where densities were less than 1.5/m^2. Tappaneir and Alm (1975) sampled five red and jack pine stands on sandy soils near Cloquet, Minnesota and report densities comparable to the average values at Squaw Lake. Basal areas for the Cloquet plots averaged 2.7 cm^2/m^2. At Squaw Lake the average density of hazel on 14 clearcut plots increased from 6.3 to 9.3 stems/m^2. At the same time, average basal areas fell from 2.7 to 1.3 cm^2/m^2. Hazel densities declined following clearcutting on two plots (E and U), while basal areas decreased on all but four (A, P, K, and G) of the 14 clearcut plots.

Unlike clearcutting, partial cutting had little effect on hazel stem densities. Average basal areas for the six partially-cut plots decreased, however, from 3.7 to 2.0 cm^2/m^2. This indicates that although some old stems were killed, sprouting was less than on the clearcut plots. The effects of logging on hazel are largely a function of mechanical processes including slash burial and stem breakage. These processes are undoubtedly more intense in a clear-cutting operation.

Following burning, the density of hazel decreased by more than 66 percent on the aspen clearcut plots (V and P) but nearly doubled on the jack pine clearcut plots (J and W). On the burned but uncut aspen plots (F and I) densities were 25.6 and 13.7 stems/m^2 compared to .1 and 6.8 stems/m^2 for plots P and V (the clearcut and burned aspen plots). Hazel basal areas were, however, very low after burning.

Of the six sample plots, none had a basal area of more than .7 cm^2/m^2. Burning killed the above-ground stems on all six plots, and the living stems sampled in 1975 were first-year sprouts that averaged no more than .2-.3 m in height.

Alban (1977) reports that annual spring burns under pine result in substantial increases in hazel stem densities. He reports that densities increased from 4.2 to 14.6 stems/m^2 on plots subjected to periodic spring burns. By comparison, annual burns completely eliminated hazel, and biennial summer burns reduced densities to 1.0 stems/m^2. Comparing these results with those from Squaw Lake suggests that hazel responds differently to burning under pine versus aspen. The lack of hazel regeneration following burning in aspen may reflect hazel's inability to compete with aspen suckers.

The response of aspen to the various treatments is in sharp contrast to that of hazel. On uncut plots densities averaged .5 stems/m^2 and basal areas averaged $<.1$ cm^2/m^2. Clearcutting increased densities to an average of 8.3 stems/m^2 on 11 plots where aspen was an important overstory component prior to logging. Average basal areas on these 11 plots increased to 1.8 cm^2/m^2. Burning of the clearcut aspen plots (V and P) resulted in large increases in density and basal area. Plot V, for example, had 23.9 stems/m^2 and 4.6 m^2 basal area/ha after cutting and burning. Prior to cutting, aspen coverage was estimated to be 23.3 m^2/ha. Thus the plot recovered nearly 20 percent of its original aspen basal area in the 2 months following burning. In contrast, the uncut aspen plot (F) had only .9 stems/m^2 and .05 m^2 b.a./ha after burning.

Peeling and burning significantly reduced aspen suckering on plot Z6. Prior to the initial cutting in 1967 aspen basal area was 28 m^2/ha (H.L. Hansen, unpublished data). Following peeling and burning it had only 5.2 stems/m^2 and .7 cm^2 basal area/m^2. These values compare with 10 and 23.9 stems/m^2 and 2.3 and 4.6 cm^2/m^2 for plots P5 and V5, respectively.

Research elsewhere leaves little doubt that clearcutting followed by a single prescribed burn is inadequate for converting aspen to pine. Buckman (1965) even suggests that a single prescribed burn following clearcutting can be used as a regeneration technique for aspen. He goes on to state that repeated spring burns can be successfully used to control aspen. A more recent study by Perala (1974) suggests, however, that this is not always true. The results of the research at Squaw Lake indicate that a single spring burn following cutting does not retard aspen suckering, although it may reduce hazel stem densities and certainly reduces hazel basal area.

Partial cutting may reduce aspen suckering. Perala (1977) suggests that leaving as little as 2.3-3.5 m^2 basal area/ha of residual aspen (5-10 percent of well-stocked stands) will reduce suckering by 35-40 percent. Data from aspen stands sampled at Squaw Lake are summarized in Table 14. Only plots D and M had residual basal areas ≥3.5 m^2/ha. Suckering on these plots was low, but other plots with little or no residual aspen also had little suckering (Q, L, and Y). Thus, the data indicate that other factors may be important in determining the extent of post-logging suckering of aspen.

Table 14. The effect of aspen overstory reduction on sucker density and basal area.

Plot	Basal Area: Initial (m^2/ha)	Basal Area: Residual (m^2/ha)	1974 Aspen Suckers: Density (stems/ha)	1974 Aspen Suckers: Basal area (m^2/ha)
A	23.7	0	12.7	2.0
V	23.4	0	9.1	1.7
Q	18.8	0	4.8	0.4
S	16.9	0	13.7	3.5
N	14.0	0	15.2	3.7
L	13.6	0	4.4	0.6
K	7.9	0	7.2	3.2
E	14.5	0.3	14.1	2.2
X	15.3	0.8	5.3	2.3
Y	13.0	0.8	4.6	0.8
U	7.3	0.6	8.5	2.1
P	11.3	1.0	6.5	1.4
D	17.3	3.5	7.1	0.7
H	9.2	1.8	6.5	1.3
M	11.3	4.4	1.6	0.1

The index of dispersion ($s^2/\overline{X}$) may be of value in evaluating the success of efforts to retard aspen suckering. Values in Table 13 generally increase following cutting. At the same time, however, stem densities increase. A reasonable goal of site conversion might be to decrease stem densities while increasing the index of dispersion. If this could be accomplished, areas of low stem density might provide space for pine to survive without the complete eradication of aspen and/or hazel. It is possible that repeated burns following logging or bark peeling could accomplish this objective. Relatively long periods of time might be required, but more time is available for site conversion in park situations compared to areas where timber production is a primary goal.

d. Herbaceous vegetation. Herbaceous vegetation at Squaw Lake was sampled intensively, in part because little quantitative data have been collected at other treatment sites in Itasca State Park. Although herbs contribute little to total biomass of mature stands, they are nevertheless important for several reasons.

Herbs may play a role in stabilizing disturbed ecosystems. Blair and Brunett (1976) found that net primary productivity of herbs following timber harvest in a southern pine ecosystem contributed almost one-fourth of the total stand productivity. Zavitkovski (1976) cites several studies and observes that, although in most stands ground-cover vegetation contributes little to total ecosystem biomass, herbaceous biomass in early successional stages of plantations may equal or exceed tree-seedling biomass.

By providing a protective cover following disturbance, herbs help stabilize soils that might otherwise be subject to wind and water erosion. Herbs may also contribute to the retention and accumulation of essential nutrients. Muller and Bormann (1976) report that *Erythronium* is vital to the conservation of nitrogen in the hardwood forest ecosystems of the Hubbard Brook Experimental Forest. This herb is a spring ephemeral that utilizes nitrate that might otherwise be lost prior to the active growth of other plants. Herbs may also contribute to the nitrogen budget of recently exposed soils. Legumes on exposed mine wastes, such as *Trifolium* and *Melilotus*, fix nitrogen and thus make nutrient deficient sites more suitable for habitation by other species (Leisman 1957).

The results of the studies of herbaceous vegetation are presented in two parts. Phytosociological data are discussed first followed by biomass and elemental composition data.

1.) Floristic analysis. Sample plots were clustered according to frequency data for species on the 15, 1 m^2 subplots. Dendrograms using both standard and absolute distance measures were produced. The most striking feature of both dendrograms is the fact that treatment had little effect on species composition or abundance on 15 of the 20 plots that were partially or completely logged (e.g. plots A3 and A4 are more similar to each other than to any other plot). The same 15 plots were identified as being most closely paired in both the standard and absolute distance dendrograms. This indicates that neither species composition nor abundance was substantially altered.

The effect of clearcutting plus burning contrasts sharply with that of logging alone. Plots V5, W5, P5, and J5 are grouped as a distinct unit in each dendrogram. In both cases the unit is joined to the remainder of the dendrogram at a high level of dispersion. Contributing to the uniqueness of the unit are high frequencies of Geranium bicknelli Britt. and Chenopodium hybridum L. The two burn-only plots (F and I) are not linked closely to the clearcut and burn plots, and both have low frequencies of Geranium and little or no Chenopodium.

Evaluating the dendrograms as a whole, both identify two distinct groups with almost identical plot compositions. Plots D3-4, H3-4, M3-4, G3-4, Y3-4, L3-4, and (in the standard distance dendrogram) N3 represent a separate group (II). The only distinguishing feature of Group II is the high frequency of Uvularia grandiflora Smith. The 1973 overstory of all plots in Group II contain aspen and birch, and the plots subjectively appeared to be more mesic than others in the study area. Group I has two subgroups, the second of which (IB) contains the clearcut and burn plots and plot R4 (standard distance dendrogram only). Subgroup IA has a few distinguishing features, although the standard distance dendrogram does group together the jack pine plots (W3, W4, J3, and J4). These plots are characterized by the presence of Cornus canadensis L. and relatively low frequencies of Aralia nudicaulis L.

The effects of treatments upon plot herb species diversity are shown in Table 15. Diversity values for individual plots represent

Table 15. Average plot herb species diversity summarized by treatment with significance based on paired t tests.

Treatment	1973	1974	1975	t	df	Significance
Clearcut	25.3	27.2	--	-1.71	11	n.s.
Partial Cut	26.6	28.6	--	-4.82	7	**
Clearcut/Burn	24.0	--	35.8	-6.08	3	**
Burn	--	--	24.5	--	--	--

n.s. - not significant
** - $p < .01$

the total number of species occurring on the 15 subplots. Partial cutting significantly increased species diversity, as did clear-cutting and burning. The increased species diversities following disturbance are a reflection of the presence of annuals such as *Chenopodium*, *Geranium*, and *Epilobium*.

The frequencies of species listed in Table 16 were significantly altered by one or more of the treatments. Table 17 lists species whose frequencies were unaffected by the indicated treatments. Only those species that occurred on three or more plots could be tested for response to the treatments, and therefore the data provide no information on the effects of cutting and burning on the less common species.

The significant increase in *Pteridium* following cutting and burning is interesting in light of the results of the pollen analysis for Squaw Lake. Periodic increases in the abundance of the spores of bracken fern appear to correlate with charcoal peaks. During the vegetation sampling, *Pteridium* was observed to produce abundant spores following burning but not following cutting.

Two species that are recorded by Ownbey (1969) as being rare or very rare in Itasca State Park and Clearwater County were observed on the study area in 1973. Single specimens of *Gentiana rubricaulis* Schwein. and *Cuscuta gronovii* Willd. were tallied on plots S and N, respectively. The two species were not recorded in 1974, but the sampling procedure used was not designed to record repeat occurrences of species that are present in low numbers, and nothing can be said of the effect of the treatments on these species.

Table 16. Herb species increasing or decreasing in frequency following specified treatments.

Species	Treatment: All Cutting	Clearcut	Partial Cut	Clearcut & Burn
Amphicarpa bracteata	− *			
Anemone quinquefolia	+ *	+ n.s.	+ n.s.	
Aster ciliolatus	− *	− n.s.	− n.s.	− n.s.
Chenopodium hybridium				+ **
Galium triflorum	+ *	+ *	+ n.s.	− n.s.
Geranium bicknellii				+ **
Lathyrus venosus	+ **	+ *	+ *	+ n.s.
Osmorhiza claytoni	− **	− **	− n.s.	− n.s.
Sanicula marilandica	− *	− *	− n.s.	− **
Uvularia grandiflora	− *	− n.s.	− n.s.	− *
Polygonum convolvulus	+ n.s.	+ *		
Calamagrostis inexpansa	+ *	+ n.s.	+ *	
Carex pensylvanica	+ *	+ n.s.	+ *	+ *
Panicum (cf. *P. oligosanthes*)	+ *			
Pteridium aquilinum	+ n.s.	+ n.s.	− n.s.	+ *

−, decrease
+, increase

n.s., not significant
*, p<.05
**, p<.01

Note: Analysis performed only when species occurred on at least three (clearcut & burn) or four (other treatments) sites before or after treatment. Where no analysis is indicated, species occurred on too few sites.

Table 17. Herb species occurring on at least three (clearcut and burn) or four (others) plots that show no significant change in frequency. Where no checks appear, species occurred on too few sites.

Species	Treatment: All Cutting	Clear Cut	Partial Cut	Clearcut & Burn
Rubus pubescens	X	X	X	X
Actea rubra	X			
Apocynum androsaemifolium	X	X	X	X
Aralia nudicaulis	X	X	X	X
Aster lateriflorus	X			
Aster macrophyllus	X	X	X	X
Clintonia borealis	X	X		
Cornus canadensis	X	X		
Fragaria virginiana	X	X	X	X
Hepatica americana	X			
Hieracium canadense	X			
Lathyrus ochroleucus	X	X	X	
Maianthemum canadense	X	X	X	X
Pedicularis canadensis	X			
Pyrola elliptica	X		X	
Solidago canadensis	X	X	X	
Solidago gigantea	X	X	X	
Streptopus roseus	X	X	X	
Thalictrum dioicum	X	X	X	X
Uvularia sessilifolia	X	X	X	
Vicia americana	X		X	X
Viola conspersa				
Viola pubescens	X			
Stachys palustris				X
Bromus ciliatus	X	X	X	X
Hystrix patula	X	X		
Oryzopsis asperifolia	X	X	X	X
Schizachne purpurascens	X			
Luzula acuminata	X	X	X	
Athyrium filix-femina	X			
Botrychium virginianum	X			

Noble et al. (1977) studied the effects of disturbance on herb communities in northeastern Minnesota and found that logging had less effect on herb communities than did wildfire and rock-raking. Their results differ from those reported here in that they observed less difference between burned and burned-plus-logged sites than between logged and unlogged sites. All of the study sites in northeastern Minnesota were at one time dominated by jack pine and black spruce (*Picea mariana* Mill. B.S.P.), and it is possible that herb communities under different overstory types respond differently to similar disturbances.

2.) Biomass and elemental analyses. Results are summarized in Table 18. Treatment effects were evaluated statistically with Duncan's New Multiple Range Test (.05 protection level) as described by Dixon (1976). Data for all plots were evaluated simultaneously. Since multiple range tests (MRT) are conservative in assigning significance to paired differences, treatment pairs were checked when their means appeared dissimilar but the MRT failed to identify significant differences. An unpaired t-test was used for this second level of analysis. The results of the t-tests are incorporated in Table 18.

Table 18 condenses large amounts of data and interpretations are, for the most part, straightforward. Above-ground herb biomass generally increased following treatments, but variability was so great that only the increases following logging-plus-burning were significant. As with other parameters, the burn-only plots had

Table 18. Summary of herb biomass and chemical analysis comparisons.

Site	Ash %	P %	K %	Ca %	Al ppm	Fe ppm	Mg %	Zn ppm	Cu ppm	Mn ppm	B ppm	Biomass gm/m^2
A	4<3	4<3*	4<3*	4<3	4<3*	4<3*	4<3*	4<3	4<3*	4<3	4<3	3<4
B	3<4	4<3	3<4	3<4	4<3	4<3*	3<4	4<3	4<3*	4<3	4<3	4<3
C												
D	3<4	4<3*	4<3	3<4	4<3	4<3	4<3	4<3	4<3*	4<3	4<3*	3<4
E	4<3	4<3*	4<3*	4<3	4<3	4<3	4<3	4<3	4<3*	4<3	4<3*	3<4
G	4<3	4<3	4<3	3<4	4<3	4<3*	3<4	3<4	4<3*	4<3	4<3*	3<4
H	4<3	4<3	4<3*	3<4	4<3	3<4	3<4	4<3	4<3*	3<4	4<3	4<3
J	5<3	5<3*	5<3*	5<3	5<3*	5<3*	5<3	5<3	5<3*	5<3*	5<3*	3<4 3<5*
												4<5*
K	3<4	4<3	4<3	3<4	3<4	3<4	3<4	4<3	4<3*	4<3	4<3	3<4
L	3<4	4<3	4<3	3<4	4<3	4<3	4<3	3<4	4<3*	4<3	4<3*	4<3
M	4<3	4<3*	4<3*	4<3	4<3	4<3*	4<3*	3<4	4<3*	4<3	4<3*	3<4
N	4<3	4<3	4<3*	3<4	4<3*	4<3*	4<3	3<4	4<3*	4<3	4<3*	3<4
P	3<4	4=3	4<3	3<4	3<4	3<4	3<4	4<3	4<3	4<3	4<3*	4<3
	5<3	3<5*	5<3	3<5*	3<5	3<5	3<5	3<5	5<3	5<3*	5<3*	3<5*
	5<4	4<5	5<4	5<4*	5<4	5<4	5<4*	4<5	4<5	5<4	5<4	4<5
Q	3<4	4<3*	4<3	3<4	4<3	4<3*	4<3	3<4	4<3*	4<3*	4<3	3<4
S	3<4	4<3*	4<3	3<4	4<3*	4<3*	4<3	3<4	4<3*	4<3*	4<3	3<4
T	3<4	4<3*	4<3	4<3	4<3*	4<3*	4<3*	4<3	4<3*	4<3*	4<3*	3<4
U	3<4	3<4	3<4	3<4	4<3	4<3	3<4	3<4	4<3	4<3	4<3	3<4
V	3<4	4<3*	4<3*	4<3	4<3*	4<3*	4<3*	4<3	4<3*	4<3	4<3	3<4
	5<3	3<5	5<3	5<3	5<3	5<3	5<3*	3<5	5<3*	5<3	5<3*	3<5*
	5<4	4<5*	4<5*	5<4	4<5	4<5	4<5	4<5	4<5*	5<4	5<4	4<5*
W	3<4	4<3*	4<3	4<3	4<3*	4<3*	4<3*	4<3	4<3	4<3*	4<3*	4<3
	5<3*	5<3	5<3*	5<3*	5<3*	5<3*	5<3*	5<3*	5<3*	5<3*	5<3*	3<5*
	5<4*	4<5*	5<4*	5<4*	5<4	5<4	4<5*	5<4	5<4	5<4	5<4	4<5*
X	3<4*	4<3	4<3	3<4	4<3*	4<3	4<3	4<3	4<3	4<3*	4<3	3<4
Y	3<4*	4<3*	4<3	4<3	4<3*	4<3*	4<3	4<3	4<3	4<3*	4<3*	3<4
Years												
3<4	13(2)	1 -	2	12 -	2 -	3	6 (1)	7	0	1	0	15
4<3	6 -	17(10)	17(6)	7 -	17 (8)	16(11)	13 (5)	12	19(15)	18 (6)	19(10)	5
3<5	0 -	2 (1)	0 -	1 (1)	1 -	1	1	2	0	0	0	4 (4)
5<3	4 (1)	2 (1)	4 (2)	2 (1)	3 (2)	3 (2)	3 (2)	2 (1)	4 (2)	4 (3)	4 (4)	0
4<5	0 -	3 (2)	1 (1)	0 -	1 -	1	2 (1)	2	2 (1)	0	0	4 (4)
5<4	3 (1)	0 -	2 (1)	3 (2)	2 -	2	1 (1)	1	1	3	3	0
Range	9.0-15.3	.21-.39	2.1-5.4	.98-1.85	.74-227	107-251	.25-.51	19.8-70.2	2.8-12.2	160-528	30-217	11.6-309.1

*, Indicates significantly different ($p<.05$) pairs.

( ), Indicates number of pairs that are significantly different ($p<.05$).

biomass values that were much lower than the clearcut-plus-burn plots. High standard deviations were associated with the mean biomass values, and this suggests that more than 15 subplots (or subplots larger than .1 m^2) should have been used. Zavitkovski (1976), however, used as many as 42,.25 m^2 plots to estimate biomass of ground vegetation in several forest types in northern Wisconsin. He found variability comparable to that reported here. Zavitkovski's biomass estimates for aspen stands are higher (90-140 g/m^2) than those for the Squaw Lake pre-treatment plots (19.0-95.4 g/m^2). The latter estimates are more typical of Zavitkovski's values for birch and northern hardwood forest types.

Concentrations of all elements except calcium were typically lower in 1974 than in 1973. Ash content was generally less in 1973. The lower 1974 concentrations may represent a dilution effect caused by increased productivity. An alternative hypothesis is that the lower 1974 values simply represent annual variations. Studies elsewhere in Minnesota indicate that concentrations of elements in forage and browse species were unusually low in 1974 (D.F. Grigal, conversation, 1978). Data from plot C (which was uncut) suggest that annual fluctuations may have occurred. Biomass estimates for plot C were about the same in 1974 as in 1973 (70.4 vs. 73.8 g/m^2). Concentrations of Al, Fe, Cu, and B, however, were all significantly less in 1974.

The fact that concentrations of most elements were less for the 1975 clearcut/burn plots than for the same plots in 1973 can more readily be explained by a dilution effect. In order to examine the question of possible biomass dilution, an analysis of covariance was used to evaluate selected data sets. Mean plot values for P and Cu (y variables) were compared with mean plot biomass values (x variable) for 1973 and 1974 data. Phosphorus was selected as a macronutrient that might be expected to be less affected by dilution than the micronutrient Cu. Because of the large variation involved in average plot biomass values, additional analyses were conducted using individual subplot values for 1973, 1974, and 1975 data from plot V. Phosphorus and Cu values were tested using 1973X1974 and 1973X1975 comparisons. The results of the different tests are summarized in Table 19.

Only the plot V comparisons for 1973X1975 show a significant change in biomass (1975 values are higher). Concentrations of P and Cu are significantly less following treatment in all but one of the comparisons. These results indicate that biomass increases generally had a significant effect on elemental concentrations. The plot V analyses are perhaps the most informative. Phosphorus concentrations do not change significantly following clearcutting-plus-burning despite the fact that biomass increases significantly. Copper concentrations, on the other hand, are significantly less in 1975 indicating a dilution effect caused by the increase in biomass production.

Biomass estimates for the 1975 plots were 3 to 9 times higher than for the 1973 plots. Although the data are not presented here, combining biomass with nutrient concentrations revealed that the

Table 19. Results of analysis of covariance for phosphorus and copper vs. herb biomass.

Test	Parameters	df	Fx	Fy	df	F
1973X1974	Biomass/P plot means	1,38	3.83(n.s.)	16.47(**)	1,37	14.95(**)
1973X1974	Biomass/Cu plot means	"	"	109.10(**)	"	94.50(**)
1973X1974	Biomass/P plot V values	1,22	0.10(n.s.)	28.40(**)	1,21	32.55(**)
1973X1975	" " " "	1,24	7.60(**)	0.79(n.s.)	1,23	3.45(n.s.)
1973X1974	Biomass/Cu plot V values	1,20	0.02(n.s.)	23.10(**)	1,19	27.8 (**)
1973X1975	" " " "	1,24	7.60(**)	21.70(**)	1,23	11.32(**)

Note: n.s.=nonsignificant (p<.05); **=highly significant (p<.01) absolute amounts of elements in the herbaceous cover increased following logging and increased significantly after logging and burning. A much more comprehensive sampling program for both vegetation and soils would have to be undertaken, however, to determine if significant amounts of the total ecosystem nutrient pool were reallocated to herbs following disturbance.

2. Soils. Soils were sampled during the course of this study for two reasons. Mineral soils were sampled for characterization purposes. The forest floor, on the other hand, was sampled intensively in an effort to determine treatment effects on selected physical and chemical characteristics.

a.) Mineral soil. Because of the time and expense involved, mineral soil sampling was limited to selected plots. Physical and chemical characteristics are summarized in Appendices G and H, respectively. Soil horizons rather than fixed depth intervals were sampled, but horizon identifications should be considered tentative.

The presence of cemented layers may have prevented the sampling of the complete soil profile at some plots. Chemical analyses indicate that the complete profile was probably sampled at plots A, D, J, M, and R4 where values for cation exchange capacity, pH, and conductivity all increase at the base of the profile. Increases were not observed at plots L, Z, E, G, and R3, and the profiles of these plots may not have been sampled completely.

The soils of Itasca State Park have developed on glacial till deposited by the Wadena lobe of the Wisconsin ice sheet (Wright and

Ruhe 1965). Because they were extensively reworked by water during the late- and early post-glacial, the park's soils are complex. As Ness (1971) observes, "horizontal and vertical soil discontinuities are common both within and between recognizable forest communities." Soils in the park have not been intensively mapped, and this lack of detailed soils information remains one of the major gaps in the characterization of the park's resources.

The three most common soils in the area are of the Menahga, Marquette, and Nebish soil series. Menahga soils are sandy and classified as Typic Udipsamments, whereas the texture of Marquette soils is generally loamy-sand. Both the Marquette soils and the silt-loam Nebish soils are classified as Typic Eutroboralfs. The Marquette soils are perhaps the most variable, especially with regard to texture. Selected horizons may vary from gravelly-coarse-sand to loamy-sand to sandy-loam. Marquette soils also appear to have the most stones.

Soils around Squaw Lake generally appear most similar to the Marquette soils, although most profiles are characterized as having sandy-loam textures. Percentages of silt are quite high (20-35 percent) at several sites. Soils formed in areas of level topography (especially at plots L and Z) have silt concentrations exceeding 40 percent and are classed as loams or silt-loams. The soil profile at plot D (also a level site) shows interbedded layers of clay and sand in the C horizon. Other soils near plot D, as well as those at plot Z, give the appearance of having been formed from parent material deposited in ponded slack water areas during the late-glacial period. These soils do not, however, have the laminations in the C horizon that characterize soils formed from lacustrine deposits.

Other soils in the study area give the appearance of having been extensively reworked by running water. This is especially true near the mouths of the streams entering Squaw Lake, most of which cut through alluvial fans composed of interbedded sand and gravel.

Chemical characteristics of the soils at Squaw Lake appear typical of the coarser-textured Eutroboralfs in the park. Ness (1971) sampled a broad range of soil conditions in the park and reports values for several soil parameters. Values for the Squaw Lake soils are in the middle of the range that Ness reports.

Although they are relatively shallow, the A1 and the overlying forest floor horizons play an important function in retaining nutrients near zones of maximum rooting. These horizons are more likely to be altered by disturbances that affect the land surface, and it is for this reason that emphasis was placed on their sampling. Phosphorus concentrations are of particular interest, for it is this element that most commonly limits productivity in aquatic ecosystems. The values in Appendix H indicate that concentrations of total P generally exceed those of extractable P by factors of 5-10 or more. This indicates that mineral and organic materials are important in retaining phosphorus in terrestrial ecosystems. Total phosphorus concentrations measured in mineral soils ranged from 20 to 1240 ppm, whereas values for total P in the forest floor ranged from 1220 to

4130 ppm. Phosphorus concentrations in the waters of Squaw Lake rarely exceed 50 μg/1.

b. Forest floor. Pre-treatment forest-floor data are summarized in Table 20. Averages are for plots of similar overstory cover type. Data from Tappeiner and Alm (1975), who sampled forest floor parameters on sandy soils near Cloquet, Minn., are included for comparison. Forest-floor chemical data from Squaw Lake are comparable to data from Cloquet except for K. At Cloquet, only K values were higher in conifer vs. deciduous stands. Concentrations of all elements are lowest for conifer stands at Squaw Lake, and I can offer no explanation for the apparent discrepancy. All values in Table 20 are for samples collected in mid- to late-summer and analysis techniques for both studies were similar.

Examination of the physical parameters for the Squaw Lake plots shows that both depth and weight of the forest floor are 1.5 to 2 times greater in conifer than in deciduous stands. Bulk densities vary little between cover types. Compared with the Cloquet data, weights of the forest floor are much higher at Squaw Lake. It seems likely that differences are related to sampling procedure and definition of the boundary between H and A1 horizons. Tappeiner and Alm took large samples (.1 m^2) using a rectangular steel frame, whereas at Squaw Lake smaller samples (.00229 m^2) were collected using an impact corer. Most of the forest-floor samples collected at Squaw Lake had a mull-type humus layer, and the transition between H and F layers was often poorly defined. Reiners and Reiners (1970)

Table 20. Comparisons between Squaw Lake forest-floor data and data from Cloquet, Minnesota (after Tappeiner and Alm 1975).

Type	Group	Plots	Depth (cm)	D_b (gm/cm^2)	Wt (gm/m^2)	P	K	Ca	Mg	Al	Fe	Zn	Cu	Mn	B
						(%)				ppm					
Aspen	I	A,D,E,Q, S,U,V,X	2.9	.09	2424	.30	.17	2.33	0.22	2857	2887	173	14.2	1125	25
Birch-jackpine jackpine	IIIA	B,T	3.1	.10	2703	.18	.05	1.61	0.17	1702	1570	71	4.2	390	16
Birch	IIIB	C,G	3.0	.09	2334	.23	.11	2.00	0.22	1726	2028	155	11.1	885	22
Aspen-birch	IV	L,M,N,Y	2.9	.08	2048	.34	.19	2.61	0.24	3469	3275	231	17.7	1443	29
Jackpine	V	J,W	4.0	.09	3008	.25	.10	1.51	0.16	3239	2644	91	8.4	1075	14
Red Pine	VI	R3	5.5	.09	4509	.19	.01	0.61	0.08	1259	1281	67	3.5	318	8
*Birch (2 stands)			--	--	603	.23	.11	1.27	0.14	1405	1594	273	11	1300	15
*Red Pine (3 stands)			--	--	1466	.18	.24	0.57	0.07	1097	1243	114	6	1169	11

Note: * indicates data from Tappeiner and Alm (1975). Underlined Squaw Lake plots were sampled only for physical characteristics.

sampled the forest floor under an oak canopy in central Minnesota and had difficulty defining A1-H layer boundaries. The fact that H and A1 layers are interwoven with fungal hyphae and rootlets further complicates the separation of the two layers. I found definition of the boundary difficult despite the fact that I took small samples that could be examined on all sides without disturbing the sample. Large samples such as those taken by Tappeiner and Alm would preclude this close scrutiny. A disadvantage of small samples is the fact that small errors in sampling are magnified greatly when values are converted to standard bulk units (e.g. g/m^2). Sample variability is also greater, because the forest floor in most stands varies considerably even over distances of 1-2 cm. Although they are generally not so deep as L + F layers, H layers are much more compact and contribute more to the total weight of the forest floor, especially in deciduous stands where litter decomposes rapidly. A1 horizons are even more compact, and the inclusion of small amounts of this layer could significantly increase estimates of forest-floor weight. The highest forest-floor values recorded at Squaw Lake were at plot R3, however, where there was a mor-type humus with a clearly defined boundary between the A1 horizon and the forest floor.

Some problems were encountered in sampling the forest floor after burning, but the Squaw Lake forest-floor weight estimates for 1973 and 1974 are comparable to those reported elsewhere in Minnesota. Reiners and Reiners (1970) estimated that the forest floor in the oak forest that they sampled weighed 52,580 kg/ha. The maximum value observed at Squaw Lake was 45,000 kg/ha at plot R3 in April 1973. Average forest-floor ash content for untreated plots at Squaw Lake ranged from 20 to 32 percent, while Reiners and Reiners report ash concentrations of 11.9 percent and 43.0 percent, respectively for the L and F layers they sampled.

In other Minnesota studies, Alban (1977) sampled the forest floor under mature red pine stands in central Minnesota and reports weights of 4380 g/m^2. In another study (Alban 1974), he found that forest-floor weights under red pine ranged from 3027 to 6053 g/m^2. Three aspen stands sampled as part of the second study had forest floor weights of 4932-7174 g/m^2. Ash concentrations reported by Alban ranged from 27 to 61 percent. Brown (1966) reports forest-floor weights under red pine of 3700 g/m^2 and Kittredge (1948) found aspen forest floors weighed 4000 g/m^2. Thus the values I report do not appear to be unusually high.

Treatment effects and temporal variation in forest-floor parameters were evaluated using the same multiple-range/t-test procedures described for the herbaceous analysis. Results are summarized in Table 21. In 1973 only physical parameters were sampled at plots D, T, U, and V. Similarly, chemical analyses were performed only on samples from plots F and I in 1975.

Depth, weight, and bulk density generally increased following logging although increases were rarely statistically significant. It is possible that logging debris on the soil surface accounted for some of the increases in depth and weight. Large amounts of slash

Table 21. Summary of forest-floor physical and chemical parameter comparisons.

Site	Ash %	P %	K %	Ca %	Al ppm	Fe ppm	Mg %	Zn ppm	Cu ppm	Mn ppm	B ppm	Depth cm	Wt. g/m^2	D_b g/cm^3
A	3<4	4<3	4<3	4<3	3<4	3<4	4<3	4<3*	4<3	4<3	3<4	3<4	3<4*	3<4
B	4<3	4<3	3<4	3<4	4<3	3<4	4<3	3<4*	3<4*	3<4	3<4*	4<3	4<3	4<3
C	4<3	3<4	4<3	3<4	3<4	3<4	3<4	4<3	4<3	3<4	3<4	4<3	4<3	4<3
D	---	---	---	---	---	---	---	---	---	---	---	3<4	3<4	3<4
E	4<3	4<3	3<4	3<4*	4<3	3<4	3<4	4<3*	4<3	4<3*	3<4*	4<3	4<3	3<4
G	3<4	3<4	4<3	3<4	4<3	4<3	4<3*	3<4*	3<4*	3<4*	3<4*	4<3	3<4	3<4
H	4<3	4<3*	4<3*	3<4	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	3<4*	3<4	3<4	3<4
J	4<3	3<4*	3<4	4<3	3<4*	3<4*	3<4	3<4	3<4	3<4*	3<4*	3<4	3<4	3<4
												5<3	3<5	3<5*
												5<4	4<5*	4<5*
K	3<4	3<4	4<3	4<3	3<4	3<4	4<3	4<3*	4<3*	4<3	3<4*	3<4	3<4*	3<4*
L	3<4*	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	4<3	4<3	3<4	3<4*	3<4
M	3<4	4<3*	4<3*	4<3	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	3<4	3<4	3<4	3<4*
N	3<4	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	3<4*	3<4	3<4	3<4
P	3<4	3<4	4<3	4<3	3<4*	3<4*	4<3*	4<3*	4<3*	4<3	3<4	5<4*	5<4	4<5
Q	3<4	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	3<4	3<4*	3<4	3<4*
S	4<3	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	3<4	4<3	4<3	4<3
T	---	---	---	---	---	---	---	---	---	---	---	3<4	3<4	3<4
U	---	---	---	---	---	---	---	---	---	---	---	3<4	3<4	3<4
V	---	---	---	---	---	---	---	---	---	---	---	4<3	4<3	4<3
												5<3	3<5	3<5*
												5<4	4<5*	4<5*
W	3<4	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	3<4*	3<4	3<4*	3<4*
												5<3*	3<5*	3<5*
												5<4*	5<4	4<5*
X	4<3	4<3*	4<3*	4<3	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	3<4*	4<3	4<3	4<3
Y	3<4	4<3*	4<3*	4<3	4<3*	4<3*	4<3*	4<3*	4<3*	4<3*	3<4*	3<4	3<4*	3<4*
A3	OC<JUL	JUL<OC*	JUL<OC*	JUL<OC*	JUL<OC*	JUL<OC*	JUL<OC*	OC<JUL	JUL<OC*	JUL<OC*	JUL<OC*	OC<JUL< AP	OC<JUL< AP	OC<JUL< AP
A4	MAY<JUL*	JUL<MA	JUL<MA	JUL<MA*	MA<JUL	MA<JUL	JUL<MA	JUL<MA	JUL<MA	JUL<MA	JUL<MA*	MA<JUL	MA<JUL*	MA<JUL*
D3	---	---	---	---	---	---	---	---	---	---	---	AP<JUL	AP<JUL	JUL<AP
J3	OC<AP< SE<JUL	JUL<AP< OC<SE	JUL<AP< OC<SE	JUL<AP< SE<OC	JUL<AP< SE<OC	JUL<AP< OC<SE	JUL<AP< OC<SE	JUL<AP< OC<SE	JUL<AP< OC<SE	JUL<AP< SE<OC	JUL<AP< SE<OC	OC<JUL< SE<MA<AP	OC<MA< SE<JUL<AP	MA<SE<OC< JU<AP
J4	JUN<AU	AU<JUN	AU<JUN	AU<JUN	AU<JUN	AU<JUN	AU<JUN	AU<JUN	AU<JUN	AU<JUN	AU<JUN	AU<JUN	AU<JUN	JUN<AU
R3	AP<OC< JUL	JUL<AP< OC	JUL<AP< OC	JUL<AP< OC	JUL<AP< OC	JUL<AP< OC	JUL<AP< OC	JUL<AP< OC	JUL<AP< OC	JUL<AP< OC	JUL<AP< OC	OC<MA< JUL<AP	OC<MA< JUL<AP	OC<MA< JUL<AP
R4	AU<JUN	JUN<AU	JUN<AU	JUN<AU	AU<JUN	AU<JUN	JUN<AU	JUN<AU	AU<JUN	AU<JUN	AU<JUN*	JUN<AU	JUN<AU	AU<JUN
Z4	JUN<AU	JUN<AU	JUN<AU	JUN<AU	JUN<AU*	JUN<AU	AU<JUN	AU<JUN	AU<JUN	JUN<AU	AU<JUN*	AU<JUN	JUN<AU	JUN<AU
Years														
3<4	10(2)	4(1)	3	4(1)	4(2)	6(2)	2	3(2)	3(2)	3(2)	15(10)	14(1)	15(5)	16(6)
4<3	6	12(9)	13(9)	12(3)	12(9)	10(9)	14(11)	13(13)	13(11)	13(9)	1	6	5 -	4 -
3<5	---	---	---	---	---	---	---	---	---	---	---	0 -	4(1)	4(4)
5<3	---	---	---	---	---	---	---	---	---	---	---	4(1)	0 -	0 -
4<5	---	---	---	---	---	---	---	---	---	---	---	0 -	2(2)	4(3)
5<4	---	---	---	---	---	---	---	---	---	---	---	4(2)	2 -	0 -
Range	16.8- 46.9	.122- .413	.007- .293	.610- 2.832	988.8- 4939.8	1280.8- 4375.0	.083- .294	65.7- 291.4	3.5- 20.8	318.1- 16.12	8.33- 207.7	0.9- 6.0	387.2- 5618.1	.06- .20

*, Indicates significantly different (p<.05) pairs, as do connecting bars (—).
( ), Indicates number of pairs that are significantly different (p<.05).

were observed on the jack pine plots (J and W), but it seems less likely that slash accumulations account for the increases observed on deciduous plots. The higher values in 1974 may simply be related to variations in sampling. In 1973 the average forest floor weight for 17 plots with deciduous overstory was 2382 g/m^2. Following cutting, average weight increased to 3031 g/m^2. Ash concentrations increased on 10 of 16 cut plots in 1974, but only from 24.4 percent in 1973 to 25.6 percent in 1974. These figures would indicate that excessive sampling of mineral soil did not occur in 1974, for ash concentrations in A1 horizons are typically 70-80 percent.

The concentrations of most elements decreased in 1974. On several plots 1974 values were significantly reduced. It is possible that the lower 1974 values represent annual fluctuations that can be related to seasonal precipitation patterns. The winter of 1972-1973 was much drier than that of 1973-1974. October 1-May 30 precipitation recorded at the park was 6.42 in (16.31 cm) in 1972-73 and 11.64 in (29.57 cm) in 1973-74. Spring runoff was noticeably greater in 1974, and it is possible that more elements were leached from the forest floor in 1974. Logging may have magnified this effect. Logging resulted in less vegetative cover and reduced interception. Input of nutrients to the forest floor via throughfall may also have been reduced. Variations in forest-floor chemical characteristics that are related to rainfall patterns may be significant in regions where periodic drought result in substantial fluctuations in annual precipitation.

In general the winter logging operation at Squaw Lake did not significantly disturb the forest floor. Only 8 of 330 randomly selected forest-floor samples had mineral soil exposed in 1974, and exposure occurred only where skid trails were used heavily. These results are similar to those reported by Mace et al. (1971), who compared the effects on soil compaction of winter and summer mechanized logging operations. Their experiments at the Cutfoot Experimental Forest near Grand Rapids, Minnesota demonstrated that compaction was significantly increased only where disturbance was heavy (i.e. skid trails and landings) and that winter logging substantially reduced the extent of heavy disturbance.

Burning had a much greater effect on the forest floor, but sampling in 1975 was complicated by the destruction of the L and F layers and the apparent movement of charcoal into the A1 horizon. I found it difficult to distinguish between H and A1 horizons and consider the analyses of the post-fire forest-floor samples to be of little value. Alban (1971), however, has recently published the results of a study to determine the effects of prescribed burning on soil properties under mature red pine. He found that annual summer burns reduce by about one-half the amount of organic matter in the forest floor. Although L and F horizons are destroyed, H horizons apparently are not. Alban reports this to be true even under the most intense burning, and it was probably also true at Squaw Lake where soils were cool and moist at the time of the mid-May burn. Alban studied the results of spring burns in addition to those discussed above and found that forest-floor reductions were less for spring burns than for summer burns.

Seasonal variations in forest-floor weight and elemental content are known to occur. Bowersox and Ward (1977) studied temporal variations of forest-floor parameters in black cherry (Prunus nigra Ait.) stands in Pennsylvania. They found that the weight of the L and F horizons was lowest in August (4000 kg/ha) and highest following leaf fall in November (6100 kg/ha). Concentrations of N, P, and K decreased between June 15 and November 15, whereas concentrations of Ca and Mg were lowest in August. The absolute amounts of all elements were highest in November.

At Squaw Lake no predictable pattern in the temporal variation of depth and weight of the forest floor was observed. The inability to detect fall increases is probably due to the fact that an integrated sample of L, F, and H horizons was analyzed. As pointed out earlier, H horizons make up the bulk of the weight of the forest floor, and spatial variations in the humus layer are probably greater than the annual increment in litter. Tappeiner and Alm (1975) estimated that litter fall ranges from 2500 to 4500 kg/ha under red pine and from 2300 to 3100 kg/ha under birch. These values are about 10 percent of the forest-floor weight for conifer and deciduous stands at Squaw Lake.

Elemental concentrations for Squaw Lake forest-floor samples do show seasonal trends. Although exceptions occur, concentrations of most elements are highest in September and October and lowest in July and August. The forest floor was sampled in April, 1973 at plots J3 and R3 and elemental concentrations were generally less than fall and greater than summer values. Temporal variability in element concentrations appears to be greater than spatial variability. Changes in the concentrations of K, which is highly mobile in forest ecosystems (Likens et al. 1967), perhaps best illustrate seasonal trends. Concentrations are highest in early autumn during leaf fall, somewhat lower in late autumn, and again lower in spring. The lowest K concentrations were measured in mid to late summer at all plots where seasonal data were collected. These results differ from those of Bowersox and Ward (1977) and indicate that the humus horizon (which I sampled and they did not) may buffer the seasonal cycling of many elements.

3. The terrestrial-aquatic interface. Water falling on land in the form of precipitation is transported to aquatic ecosystems either as surface flow via streams or as subsurface groundwater flow. Surface runoff outside of channelized streams rarely occurs in forested landscapes (Pierce 1966, Kirkby and Chorley 1967, Megahan 1972). In this study emphasis was placed upon sampling channelized surface flow. The streams flowing into Squaw Lake are ephemeral and are strongly influenced by both temporal precipitation variations and the intensity of individual rainfall events. A limited amount of groundwater data were collected, and these are also discussed.

a. Precipitation. Daily precipitation data are graphed with stream discharge data in Figure 14. Data are only for the period when the stage-height recorder at the flume was in operation (approximately April 1 thru October 31). The daily totals were taken from the recording rain gauge charts and represent a single sampling point in the middle of the Squaw Lake treatment area. During April-July, 1975 the recording rain gauge was maintained at the Forestry and Biological Station (FBS). The rain gauge was operated at the station during the winter months and was not re-established at Squaw Lake in April 1975 because the area where it was normally located was part of the proposed burn.

Monthly summary data for the period November 1, 1972 to July 31, 1975 are presented in Table 22. Data for both the recording rain gauge and a storage rain gauge (SRG) located at the FBS are included. According to the SRG, precipitation during 1973 was more than 4 in (10.2 cm) greater than normal, whereas that during 1974 was 1 in (2.5 cm) less. Precipitation totals for the period November 1 to May 31 were 16.3 cm (1972-73), 29.6 cm (1973-74), and 33.2 cm (1974-75). Monthly totals vary substantially between the two rain gauges, especially for months when the RRG was at Squaw Lake. The differences probably reflect normal spatial variations in precipitation. Comparisons of daily totals for the two rain gauges show that differences are greatest when intense summer rainstorms are sampled. These storms deliver large amounts of water in short periods of time, but rarely affect large areas uniformly. Several such storms were recorded at Squaw Lake. They significantly affected streamflow as measured at the flume and will be discussed more fully in conjunction with the stream-discharge data.

Table 22. Monthly precipitation summaries for the period November 1, 1972 - July 31, 1975 for the storage (SRG) and recording (RRG) rain gauges.

Month	1972 SRG	1972 RRG	1973 SRG	1973 RRG	1974 SRG	1974 RRG	1975 SRG	1975 RRG
January			.09	-	.61	.72	2.34	2.69
February			.29	-	.57	.58	0.46	0.67
March			1.28	-	.91	1.18	2.28	1.72
April			1.39	-	2.95	2.73*	2.92	3.29
May			1.50	1.82*	4.22	3.69*	2.15	
June			3.85	5.44*	1.92	1.55*	6.54	
July			7.03	7.58*	3.48	3.94*	1.66	1.67
August			1.95	1.86*	4.46	4.51*	-	-
September			7.06	8.38*	0.46	0.34*	-	-
October			2.41	2.86*	1.61	2.03*	-	-
November	.37		1.23	1.37*	1.91	2.04*	-	-
December	1.50		1.15	1.28	1.00	0.93	-	-
Annual Total			29.23		24.10			

*indicates gauge located at Squaw Lake.

b. Throughfall quantity and quality. Throughfall is a significant pathway by which elements are transferred from vegetation to soils in terrestrial ecosystems. At Squaw Lake, intensive sampling was conducted to determine the effects of cover type on throughfall quantity and quality. Some nitrate and Kjeldahl nitrogen data were collected, but primary emphasis was placed on sampling P.

Phosphorus is tightly bound by organic matter in foliage and by organic and mineral matter in soils. The P fraction that moves via throughfall, however, is highly mobile and is thus capable of being lost to aquatic ecosystems via runoff. If P concentrations vary with cover type, then cover type could potentially affect productivity in aquatic ecosystems where P is limiting. Nitrate and Kjeldahl nitrogen were sampled primarily in response to the interest in nitrogen cycling that arose following the Hubbard Brook studies.

Data for throughfall quantity, orthophosphate ($PO_4^{=}$), total phosphorus (TP), nitrate (NO_3^-), and Kjeldahl N are summarized in Appendix I. Significant differences between means were determined by comparing 95 percent confidence intervals ($\overline{X} \pm t_{.05} s_{\overline{X}}$). The results of these comparisons are summarized in Table 23. Plot means for throughfall quantity, TP, and NO_3^- are expressed as a percent of the same parameters for bulk precipitation in Table 24. Comparisons for $PO_4^{=}$ are not included in Tables 23 and 24 because they paralleled those for TP. The results of the phosphorus sampling showed that TP usually is composed of at least 50 percent $PO_4^{=}$ and that during fall

Table 23. Summary of significance tests for throughfall parameters. Comparisons above the diagonal lines are for 1972-1973; those below the diagonal lines are for 1974. Numbers in ( ) are total comparisons for the indicated time period.

Total P

	A	Z	J	R3	R4	X
A		*	2	4	*	7
Z	1		*	*	*	*
J	1	3		2	*	7
R3	*	*	*		*	5
R4	0	1	1	*		*
X	3	4	2	*	3	

1972-1973 (10)

1974 (5)

NO_3^-

	A	Z	J	R3	R4	X
A		*	2	3	*	3
Z	*		*	*	*	*
J	0	*		1	*	5
R3	*	*	*		*	8
R4	*	*	*	*		*
X	0	*	1	*	0	

1972-1973 (10)

1974 (5)

Table 23. Continued

Throughfall Quantity

	A	Z	J	R3	R4	X
A		*	2	4	*	2
Z	1		*	8	*	*
J	0	1		2	*	6
R3	*	*	*		*	6
R4	1	0	1	*		*
X	2	3	0	*	2	

1972-1973 (7)

1974 (5)

*No comparison

Table 24. Summary of the effect of cover type and treatment on throughfall parameters.

Plot	Cover	Sept.	April	May	June	June	July	July	Aug.	Sept.	Oct.	Dec.	May	July	Aug.	Sept.	Nov.
							Throughfall Quantity										
A	Aspen	91	--	60	87	86	87	--	--	--	81	92	98	95	75	71	96
Z	Aspen	--	--	--	--	--	--	--	--	--	--	--	97	80	80	80	83
J	Jack pine	64	--	52	72	78	70	--	--	--	85	78	96	84	95	100	92
R3	Red pine	70	--	50	70	75	73	--	--	--	71	59	--	--	--	--	--
R4	Red pine	--	--	--	--	--	--	--	--	--	--		97	100	81	89	82
							Total P										
A	Aspen	--	288	1015	1275	744	1200	663	1828	2244	8307	196	200	272	1329	1504	8029
Z	Aspen	--	---	---	---	---	---	---	---	---	---	---	73	647	845	1556	8741
J	Jack pine	--	155	192	564	739	1260	263	2594	2150	8113	403	169	270	555	907	1706
R3	Red pine	--	136	154	736	717	927	174	894	325	1260	214	---	---	---	---	---
R4	Red pine	--	---	---	---	---	---	---	---	---	---	---	85	195	426	1381	4247
							NO_3^-										
A	Aspen	102	---	250	101	27	144	342	149	52	173	104	110	137	111	114	75
J	Jack pine	128	---	768	427	175	184	242	217	111	196	403	119	172	162	210	139
R3	Red pine	203	---	810	491	200	203	280	316	117	273	491	---	---	---	---	---

[1]Values are expressed as a percent of bulk precipitation

sampling periods 75 percent or more of all TP is in the form of $PO_4^{=}$. It is questionable whether these percentages represent actual conditions in fresh throughfall, however. Water usually sat in the field for 3-4 weeks or more before sampling, and it is likely that changes in the state of P occurred. The amounts of $PO_4^{=}$, nevertheless, appear much greater in throughfall than in lake surface water, where $PO_4^{=}$ is usually less than 10 percent of TP.

The problems associated with throughfall sampling were most evident in July, 1973 when animal destruction and sampler overflow combined to produce poor results. Even with fifteen samplers at a plot, standard errors were as much as 50 percent or more of mean values for most parameters. Reduction in sample sizes to 5-10 samplers greatly reduced the possibility of detecting significant differences. Variability in the case of P occasionally appeared to be associated with contamination. This was especially true for bulk precipitation samples where birds perched on the sampler rims and defecated in the funnels. This type of contamination was usually obvious, and values were not included in computations. As a general rule, values that exceeded the mean of other samples by a factor of 10 were rejected. Except for the contamination by birds, averages for bulk precipitation samples were less variable than those for throughfall samplers, and five samples appeared sufficient to obtain estimates for bulk precipitation that were no more variable than for throughfall.

Table 24 shows that interception under conifers was generally 10-15 percent greater than under aspen in 1973. Interception was slightly greater for red pine than for jack pine during the summer. After leaf fall, differences were greater, and this probably reflects the importance to interception of the dense hazel understory in the jack pine plot. The fact that throughfall increases in October for jack pine and not until December for aspen may reflect the fact that leaf fall occurs somewhat earlier for hazel than for aspen.

After clearcutting little interception occurred until mid to late summer. The effects of revegetation are most obvious at plot A, where aspen sprouted vigorously. In comparison, little interception occurred at plot J during all of 1974. By mid summer interception at plot A was greater than at the eight-year-old aspen sapling stand (Z), and interception at both plots was greater than or equal to interception at the mature aspen stand (A in 1973). At plot R4, however, interception was less than that under mature pine (R3 in 1973) and less, also, than that under one-year-old aspen (A in 1974).

At Squaw Lake, interception under hardwoods appears comparable to that observed by Helvey and Patric (1965). They summarized the results of several interception studies and conclude that interception is typically 10 percent under hardwoods in the eastern United States. The well-developed hazel and herbaceous understories at Squaw Lake may account for the slightly higher interception values there. Helvey (1971) summarized rainfall interception studies under conifer stands and reports that interception averages 13 percent under red pine. The greater interception at Squaw Lake may reflect the dense canopy of red pine (R3 in 1973) and the dense hazel understory under jack pine (J in 1973).

Forest canopies greatly increased total phosphorus concentrations in throughfall compared to those in bulk precipitation. The latter rarely exceeded 20–30 μg/l, whereas the former exceeded 1 mg/l under aspen in the fall. Table 24 shows that even under red pine TP may be 5 to 10 times higher than in the open. The greatest increases, however, can be attributed to the presence of deciduous cover. Values under jack pine are usually higher than under red pine, especially in the fall, and hazel apparently contributes significant amounts of P to throughfall.

Clearcutting reduced P concentrations only during the first two sampling periods in 1974. The lack of revegetation at plot J in 1974 is reflected in the lower TP concentrations compared to the other three plots. Concentrations under eight-year-old red pine were less than under one- and eight-year-old aspen but were higher than under pole-sized red pine (R3 in 1973). These higher values reflect the presence of scattered hazel clones in the sapling red pine stand. Although total phosphorus concentrations were highly variable except in bulk precipitation, significant differences occurred between canopy types (Table 23). Concentrations under aspen were significantly greater than under red pine during 4 of 10 sampling periods in 1972–73. Significant differences occur during spring and fall only, with summer values showing little difference.

The results of phosphorus sampling for throughfall at Squaw Lake differ from those reported by Wells et al. (1972) who studied nutrient cycling under pine and hardwood forests in North Carolina. They report mass-balance values (in kg/ha), and their data are for the entire growing season, but they found that throughfall delivered .74 kg/ha P under pine compared to only .61 kg/ha under hardwoods. The pine stand sampled by Wells et al. contained a hardwood understory, however, and they note that this understory "was quantitatively important to nutrient cycling." The comparison between the Squaw Lake and North Carolina studies should perhaps best be made on the basis of plots J and A at Squaw Lake. In 1973 significant differences in TP concentrations for these two plots were observed only in April and June.

The seasonal pattern in phosphorus concentrations is striking and differs from results presented by Eaton et al. (1973) who sampled throughfall under a northern hardwoods forest at the Hubbard Brook Experimental Forest, New Hampshire. They found that $PO_4^=$ concentrations generally declined from .4-.5 mg/l in June to .2-.3 mg/l in October. Eaton et al. employed a different sampling schedule from that used at Squaw Lake, however. They collected throughfall and cleaned out the funnels of their collectors weekly, and it is possible that much of the P observed at Squaw Lake leached from leaves that had collected in funnels. At Hubbard Brook increases in some parameters (e.g. K, organic carbon, N, and Ca) were observed in autumn, however, and it seems unusual that no increase was observed in $PO_4^=$.

In contrast to TP, nitrogen appears to cycle more rapidly in pine than in hardwoods at Squaw Lake. Table 24 shows that nitrate concentrations under aspen are rarely more than 2 times those in bulk precipitation and are occasionally less. In throughfall under pine, however, NO_3^- is as much as 4-8 times higher than in bulk precipitation. Differences are greatest in spring and fall and are quite comparable for red pine and jack pine. Because plots A and J had a hazel understory and R did not, it would appear that the nitrate increases are related to the presence of conifers. Wells _et al._ (1972) also observed high NO_3^- loading under pine compared to hardwoods. Regional variations in nitrate concentrations in throughfall appear to exist. At Hubbard Brook, Eaton _et al._ (1973) report values for NO_3^- in bulk precipitation and throughfall that are 5-10 times those observed at Squaw Lake. Average weighted concentrations (June 1-October 28) were .98 mg/l for precipitation and 1.88-3.29 mg/l for throughfall in New Hampshire.

Only a limited amount of Kjeldahl N sampling was done in 1973, and values in Appendix I represent analyses of single samples pooled from all collectors at a site. There appears, however, to be a clear pattern of higher concentrations under pine. Values range from .27 mg/l in bulk precipitation to 2.5 mg/l for throughfall in pine stands. These higher K values parallel the higher nitrate concentrations and indicate that nitrogen conservation is less in conifer ecosystems. At Hubbard Brook, NO_3^- comprised almost 50 percent of the total N in throughfall, whereas at Squaw Lake NO_3^-

accounted for only 20-30 percent of total N. Overall, less than one-third as much N is being cycled at Squaw Lake compared to Hubbard Brook.

c. Groundwater. The results of the two groundwater analyses are shown in Table 25. They indicate that groundwater near Squaw Lake has both high concentrations of calcium and magnesium and high conductivity but has relatively low concentrations of phosphorus and nitrogen. There are no published data available for groundwater quality in the Itasca area, but the high cation concentrations are to be expected, because the Itasca moraine is composed of calcareous till. Groundwater data will be compared with water quality data of streams and lakes when they are discussed.

d. Streams. The watershed of Squaw Lake (as shown on Plate 2, p. 25) has an area of 5400 acres (2187 ha) and is drained by four primary streams (PST, MST, SWST, and SST). Two other streams (BST and SEST) contribute a limited volume of water. The two streams at the south end of lake (SST and SEST) pass through a marshy area before entering Squaw Lake, whereas the other streams enter it directly.

1.) Discharge. All six streams were ephemeral during the study period. Peak flows occurred during the spring, and BST and SEST flowed only for brief periods when snow melt was greatest. Gould Creek, the outlet of Squaw Lake, was also ephemeral during the study period. Squaw Lake abandoned its outlet for brief periods during August in both 1973 and 1974. A water balance of in- and out-flowing

Table 25. Water quality parameters for Squaw Lake area groundwater.

Site	Ca^{++}	Mg^{++}	PO_4^{-}-P	Total P	NO_3^{-}-N	Kjeldahl-N	Fe	Cond.
			mg./l.					μ mho/cm^2
Squaw Lake Camp	46.6	22.8	.005	.100	.106	.17	.02	473
Gould Creek seep	51.3	22.2	.002	.048	.045	.10	.00	517

surface water was calculated on two occasions, May 17, 1974 and April 23, 1975. Discharge data for these two dates are presented in Table 26. Measurements were made during the peak of spring runoff in 1975 and one week after a heavy rainstorm on May 10-11, 1974. On both dates SWST contributed more than 50 percent of the water entering the lake.

Annual discharge data for PST are presented in Figure 14. The flume was calibrated in the field by measuring flow rates with a current meter 10 times in 1974 and 1975. A power curve with the equation $y = .0023x^{2.65}$ was fitted to the resulting data ($r = .98$). The equation allows the calculation of discharge (y) in cfs when stage height (x) is measured in inches. Flow exceeded the capacity of the flume only on May 11, 1974. Two inches (5 cm) of rainfall fell during a 28-hour period on May 10 and 11, and flow at the flume probably exceeded 5 cfs. The impact of the May 10-11 storm on stream sediment load and the limnology of Squaw Lake will be dealt with in detail in following sections.

Maximum discharge during spring snow melt occurred during the third week of April in 1974 and 1975, when flow rates exceeded 1.4 and 2.2 cfs, respectively. In 1973 maximum discharge occurred about April 10 and reached a recorded maximum of only .20 cfs. It should be noted that discharge rates during early spring are, to some degree, approximations, since the stilling well of the flume occasionally froze at night.

Table 26. Surface water balance for Squaw Lake (discharge in cfs).

Stream		17 May 1974	23 April 1975
Input:	PST	0.74	2.20
	BST	0	0.88
	MST	0.45	6.15
	SWST	3.10	1.10
	SST	1.34	1.33
	SEST	0	0.38
Output:	Gould Creek	-10.32	-4.62
	Net	-4.69	+7.42

Significant increases in discharge occurred in 1974. Without long-term calibration data, however, it is impossible to relate increases to the effects of logging. Several studies (Douglass and Swank 1972, Harr 1976, Likens et al. 1970, Verry 1974) have shown that streamflow increases following logging, and timber cutting probably had some effect on the discharge of PST. In addition to treatment effects, seasonal variations in precipitation were important in determining streamflow since discharge from PST appeared to be related to water levels in Pond North and Pond South. These levels were low after the dry winter and spring of 1973 but rose rapidly as rainfall increased in July, 1973. By September, 1973 heavy rains had exceeded the ponds' storage capacity, and PST discharge responded rapidly to precipitation events. A period with little rainfall occurred in August and September 1974, but above normal precipitation during the winter of 1974-75 resulted in heavy discharge the following spring. Heavy rainfall in May and June, 1975 resulted in much higher discharges compared to June, 1974.

Not all variations in discharge were related to precipitation. For brief periods in June, 1974 and July, 1975, discharge at the flume showed a diurnal pattern. Flow increased during late morning and early afternoon and fell again in late afternoon. This pattern probably reflects a delayed response in streamflow to decreased evapotranspiration during the night.

Discharge at the flume ceased on April 28, 1973, on June 16, 1974, and on July 18, 1975. Following abandonment of the flume, surface flow in PST gradually receded up the channel until a rainfall event caused flow to increase. The stream's response to individual precipitation events varied depending upon initial flow rates, intensity of rainfall, and the amount of rainfall occurring in preceding days and weeks. For brief periods in 1973 and 1974, flow ceased along the entire length of PST.

Although the other five streams draining into Squaw Lake were observed less frequently, all ceased contributing surface water at some time during the summers of 1973 and 1974. SWST was typically the last to abandon its outlet and did so for only brief periods in late summer.

2.) Water quality parameters. Temperature and dissolved oxygen data for PST varied seasonally and at the three sampling points on a given date. Values at PST3 usually approximated those for the surface water of Pond South. When flow was present, temperature and oxygen values at PST2 were similar to those at PST3, but temperature generally decreased between PST2 and PST1, and dissolved oxygen concentrations rose. Between late spring and early fall stream temperatures were typically 3-4^{o}C lower at PST1, whereas dissolved oxygen concentrations were 1-2 mg/l higher. During the summer the temperature of water flowing through the flume rarely exceeded 17-18^{o}C. In comparison, temperatures at PST3 were usually 20-23^{o}C. Dissolved oxygen concentrations at the flume (PST1) were at or near saturation levels, especially during spring runoff, when values typically exceeded 10-11 mg/l. When flow ceased, dissolved oxygen concentrations fell sharply at PST2 and PST3. Water was confined to small pools at these sampling sites, and decomposition of organic matter in the stream bed reduced dissolved oxygen to less than 1.0 mg/l on a few occasions.

Conductivity data for PST during 1973 and 1974 are presented in Figure 15. During periods of flow, values were typically lowest (25-50 μmho/cm^2) at PST3. Values usually were about 5 units higher at PST2 and 10 units higher at PST1. This pattern is obvious only for the 1974 data, for flow was limited to brief periods during much of 1973. During 1974 values generally increased from May to October at all sites. This may reflect increased contributions of groundwater relative to ponded surface water as flow-rates decreased. The sharp peaks at both PST2 and PST3 during the summer of 1973 represent periods when flow ceased. Dissolved oxygen concentrations fell simultaneously, and high conductivities may reflect the release of cations by organic matter decomposition and/or the increased effect of groundwater.

Conductivity data for 1975 are presented in Figure 16b. Four streams (PST, BST, MST, and SWST) were sampled. Conductivities were lowest during April snowmelt. The lowest values recorded were for BST reflecting the dependence of this stream on surface flow. In all streams conductivities increased with decreasing flow. On June 1, 1975 SWST had a conductivity nearly twice that of PST, indicating that SWST receives more water via subsurface flow. This subsurface contribution is probably responsible for the more persistent

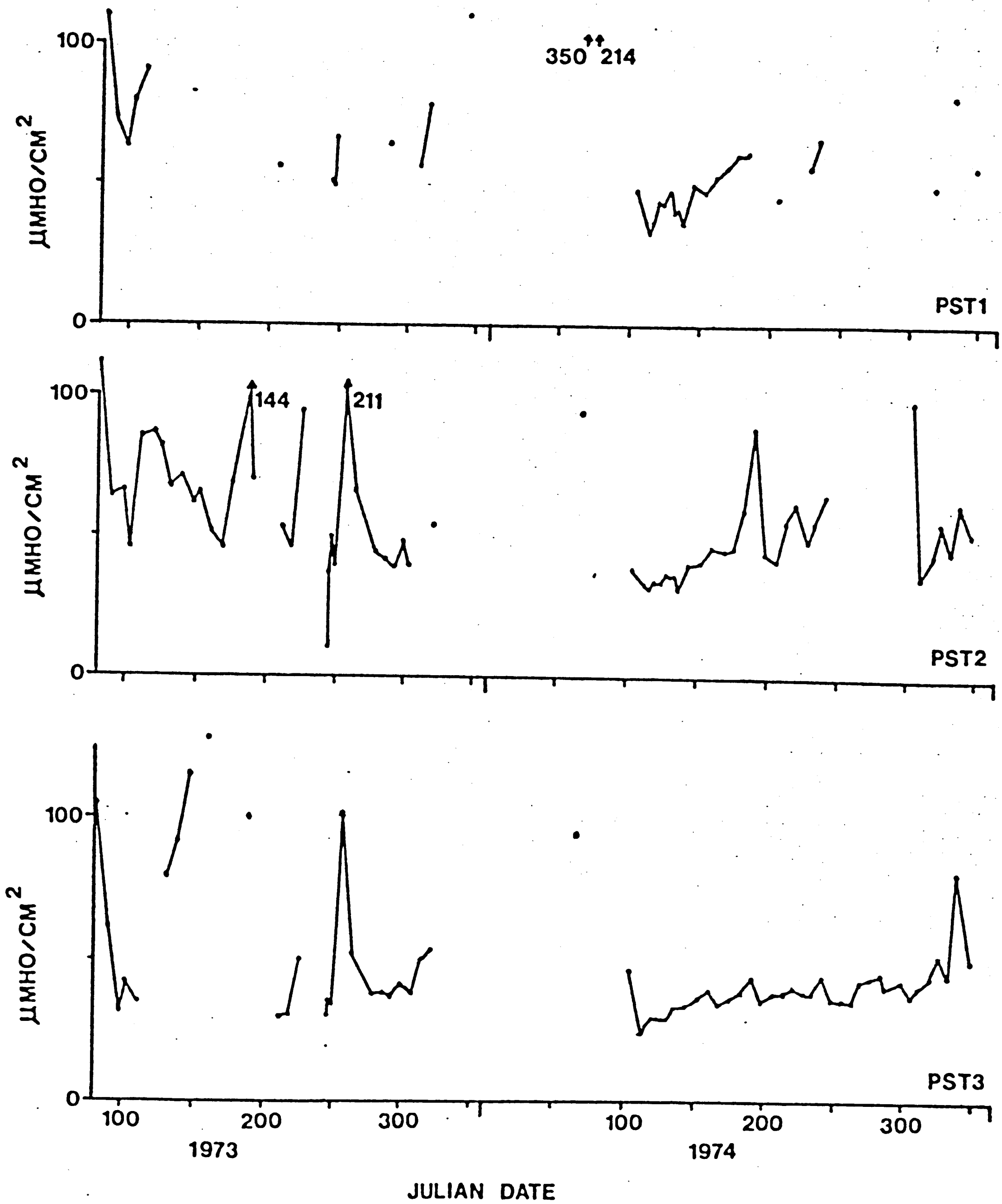


Figure 15. Conductivity data for PST sampling stations, 1973-1974.

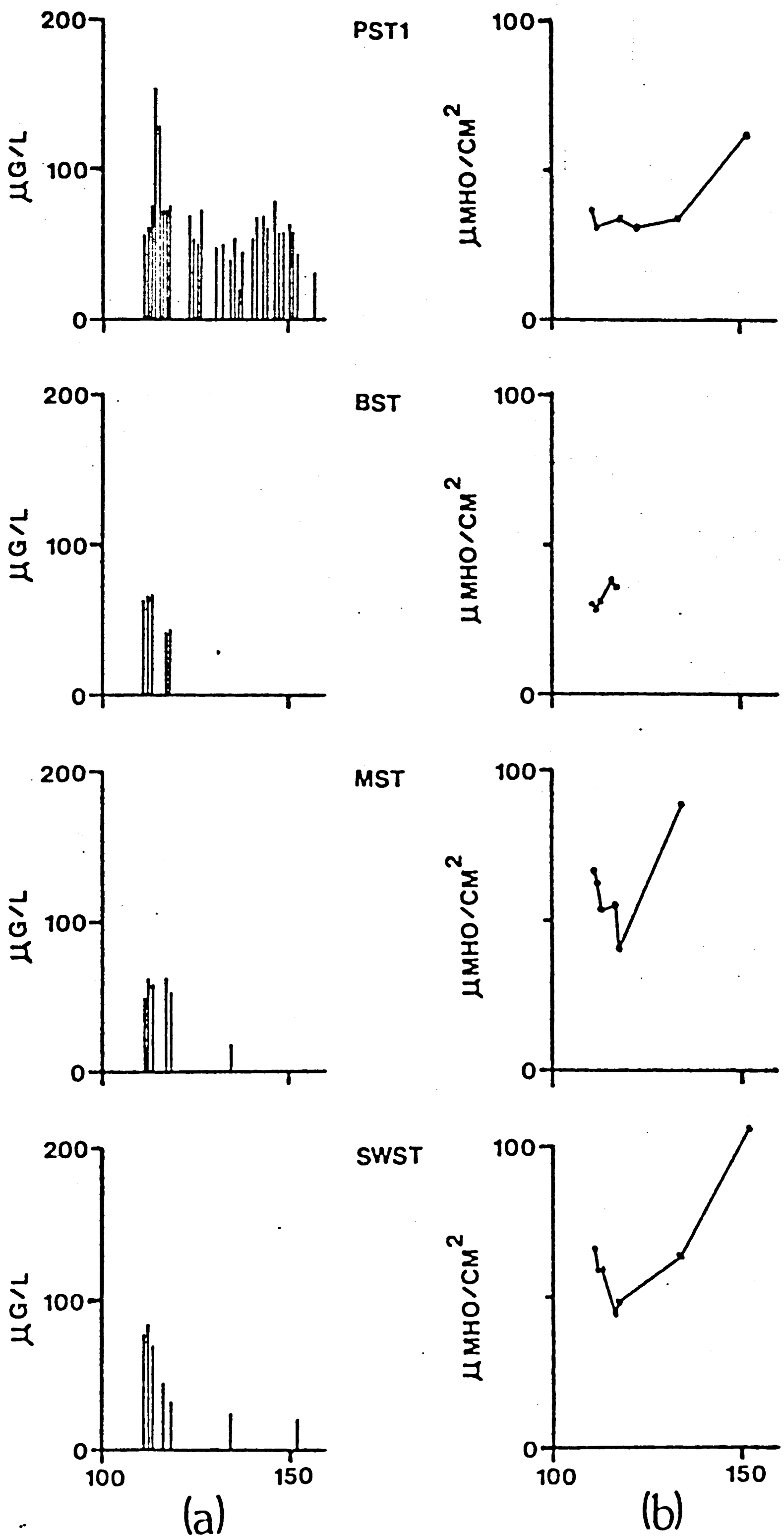


Figure 16. Phosphorus (a) and conductivity (b) data for 1975 stream samples.

flow in SWST during late summer.

Concentrations of total phosphorus (TP) for PST1, 2, and 3 are presented in Figures 17 (1973) and 18 (1974). Concentrations are generally lowest in the fall. The high concentrations that occur during peak runoff in the spring are probably related to increases in suspended particulate matter that occur in conjunction with increased flow. High values in the summer were observed at PST1 on several occasions and at first were difficult to interpret. A careful examination of the data for the three sampling sites on PST reveals a possible explanation, however. As flow decreases during mid-summer dry spells, water is restricted to small pools such as those at PST2 and PST3. When flow stops altogether, conductivity increases and dissolved oxygen decreases. At the same time TP values increase dramatically. On August 14, 1973, for example, TP at PST2 reached 445 μg/l. Conductivity was 93 $\mu mho/cm^2$, and no dissolved oxygen was detected. When rainfall sufficient to produce flow occurs, the pools of water are flushed out. The water at the head of the flow is enriched by the water from the pools and has higher concentrations of phosphorus. This pattern is best illustrated by data collected between September 2 and 6, 1972. Total phosphorus and discharge are shown on Figure 19. A sample taken as water first trickled through the flume had 142 μg/l TP. Concentrations then decreased, and by September 6, when flow through the flume had ceased, the concentrations of TP in a sample taken upstream was only 40 μg/l. This general pattern was observed on several other occasions during

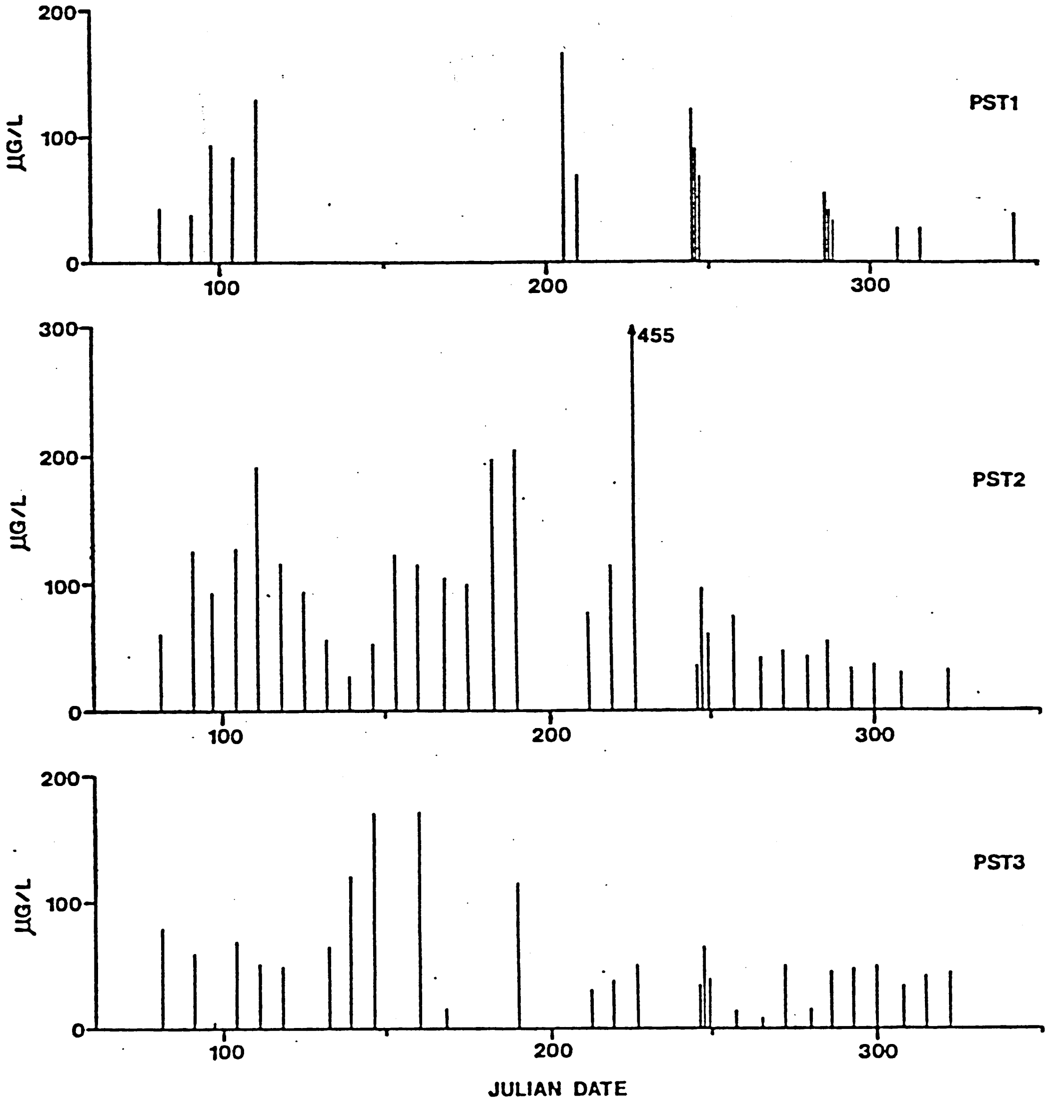


Figure 17. Total phosphorus data for PST1, 2, and 3; 1973.

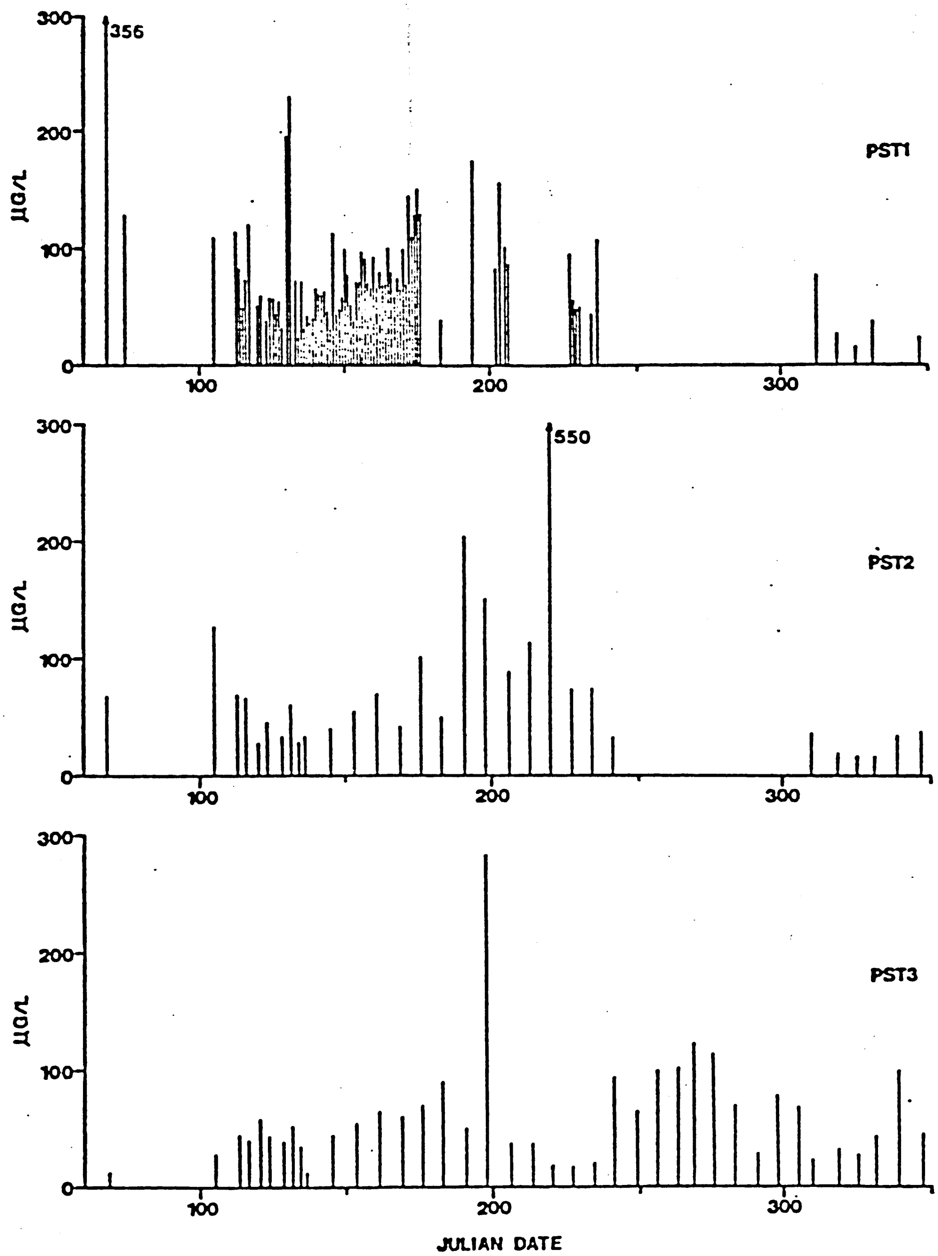


Figure 18. Total phosphorus data for PST1, 2, and 3; 1974.

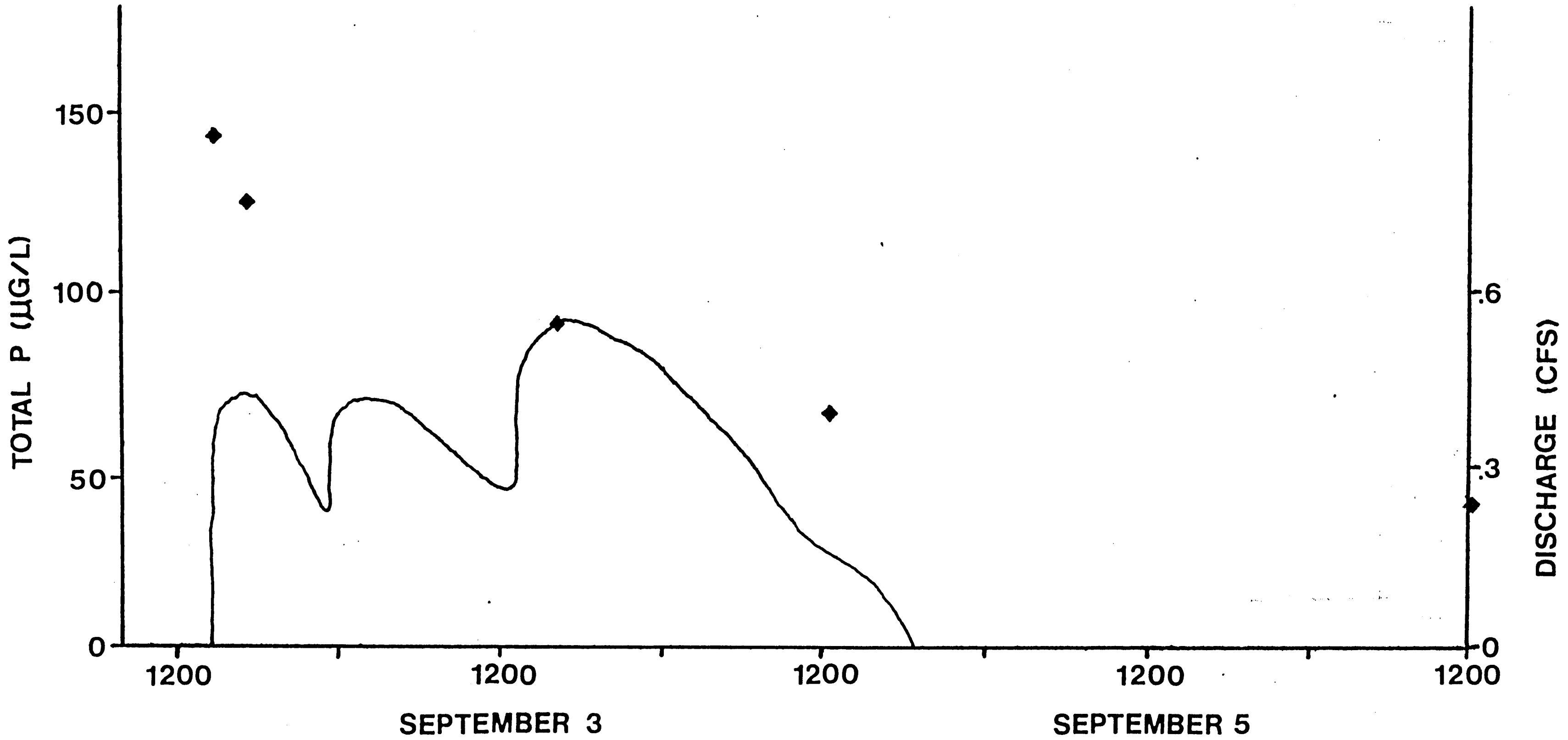


Figure 19. Total phosphorus and discharge data for PST1; September 2-6, 1973.

the summers of 1973 and 1974.

Phosphorus concentrations for the streams sampled in 1975 are graphed in Figure 16a. Phosphorus was sampled more intensively at PST1, but all streams show decreasing phosphorus concentrations with increasing conductivity. This pattern indicates that groundwater may be contributing proportionately less phosphorus than surface flow.

Only a limited amount of nitrate data were collected at PST1, and these are depicted in Figure 20. Although seasonal and annual fluctuations were observed, there were no apparent treatment effects. At Hubbard Brook, Likens _et al_. (1972) found that stream-water nitrate values increased to more than 50 mg/l following destruction (by clearcutting and herbicide treatment) of a northern hardwoods ecosystem. Several factors account for the lack of such a response at Squaw Lake. At Hubbard Brook soils rarely freeze during the winter. As a result, organic N is mineralized to NH_4^+ during the winter and early spring by heterotrophic decomposing bacteria. As spring snowmelt proceeds, NH_4^+ in excess of that needed by heterotrophs "trickles" out of the organic matter and is converted by nitrifying bacteria first to NO_2^- and then NO_3^-. Excess NO_3^- is normally utilized by higher plants as they leaf out in June, but vegetation destruction blocks biological uptake, and the excess NO_3^- is carried through shallow, porous soils to streams.

At Squaw Lake, soils freeze to a depth of several decimeters each winter. It is unlikely, therefore, that extensive mineralization of organic N occurs. Even if excess NO_3^- were to accumulate, it is

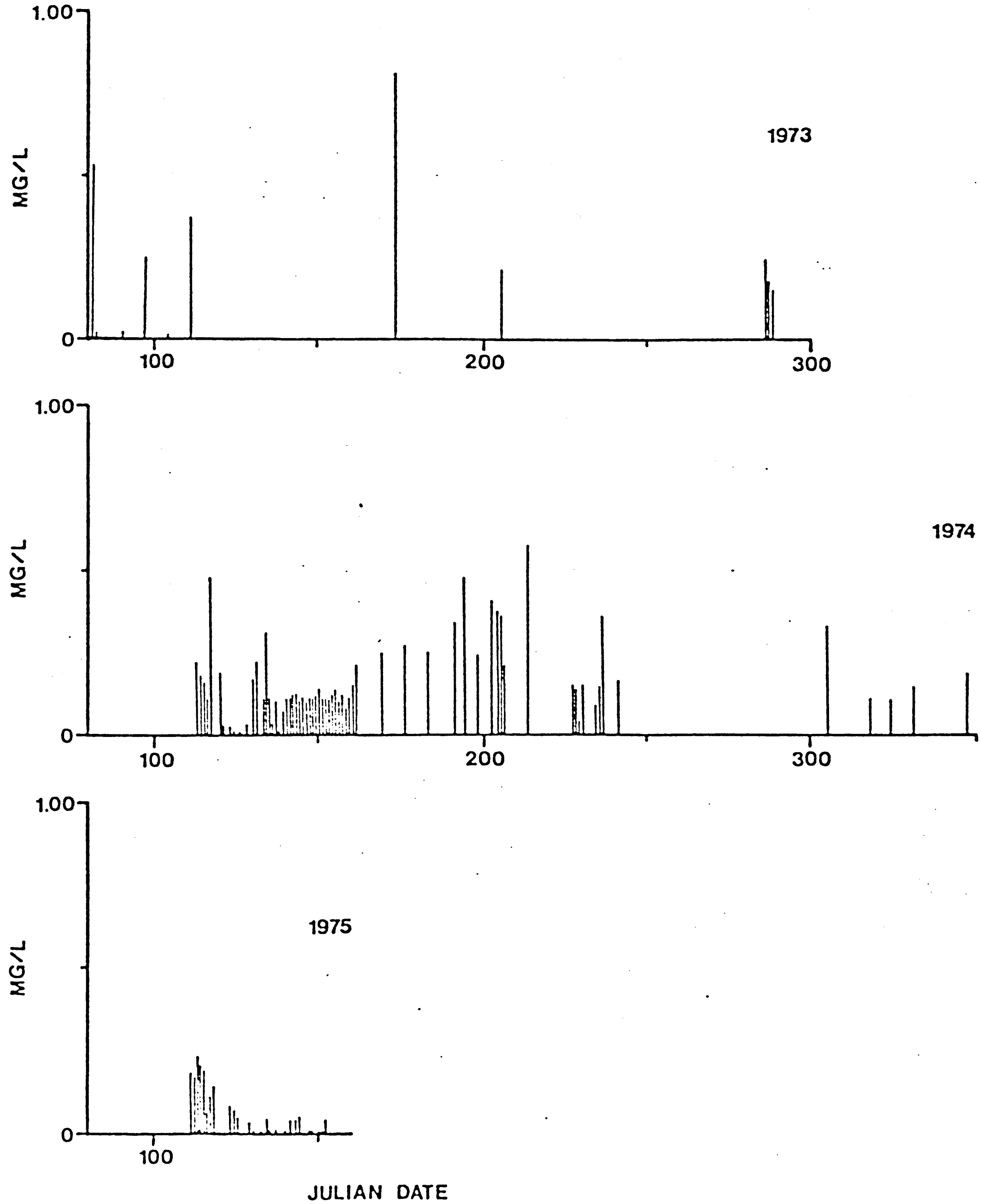


Figure 20. Nitrate data for PST1, 1973-1975.

unlikely that it would be transported to Squaw Lake via streamflow. Precipitation in Minnesota is less than 60 percent of that in New Hampshire, and soils are deeper and of finer texture. Thus, less water is available for movement through the soil profile, and its flow is restricted. Williams (1974) has reported increases in soil-solution NO_3^- concentrations following logging of conifer stands in northeastern Minnesota. At Squaw Lake, however, any excess NO_3^- that may have been produced following logging was probably taken up by vegetative regrowth. In order to successfully convert the Squaw Lake treatment area to pine it will be necessary to inhibit the vegetative reproduction of aspen and hazel. If this can be accomplished, nitrate concentrations in stream water may increase, and they should be monitored during future treatments.

The transport of particulate matter was monitored at PST1 in 1974, and at PST, BST, MST, and SWST in 1975. Data for PST1 (1974) are presented in Figure 21. Total particulate matter (TPM) was composed of about 50 percent particulate inorganic matter (PIOM) and 50 percent particulate organic matter (POM) except during periods of heavy flow. As flow increased, TPM increased sharply especially during the May 10-11 storm. Increases were largely the result of increased PIOM transport. Figure 21 indicates that when discharge exceeds 2 cfs inorganic material are washed into the lake. Although stream samples were not examined microscopically, it seems likely that the PIOM is composed largely of silt-sized particles. Soils in the area contain as much as 40-50 percent silt, which generally

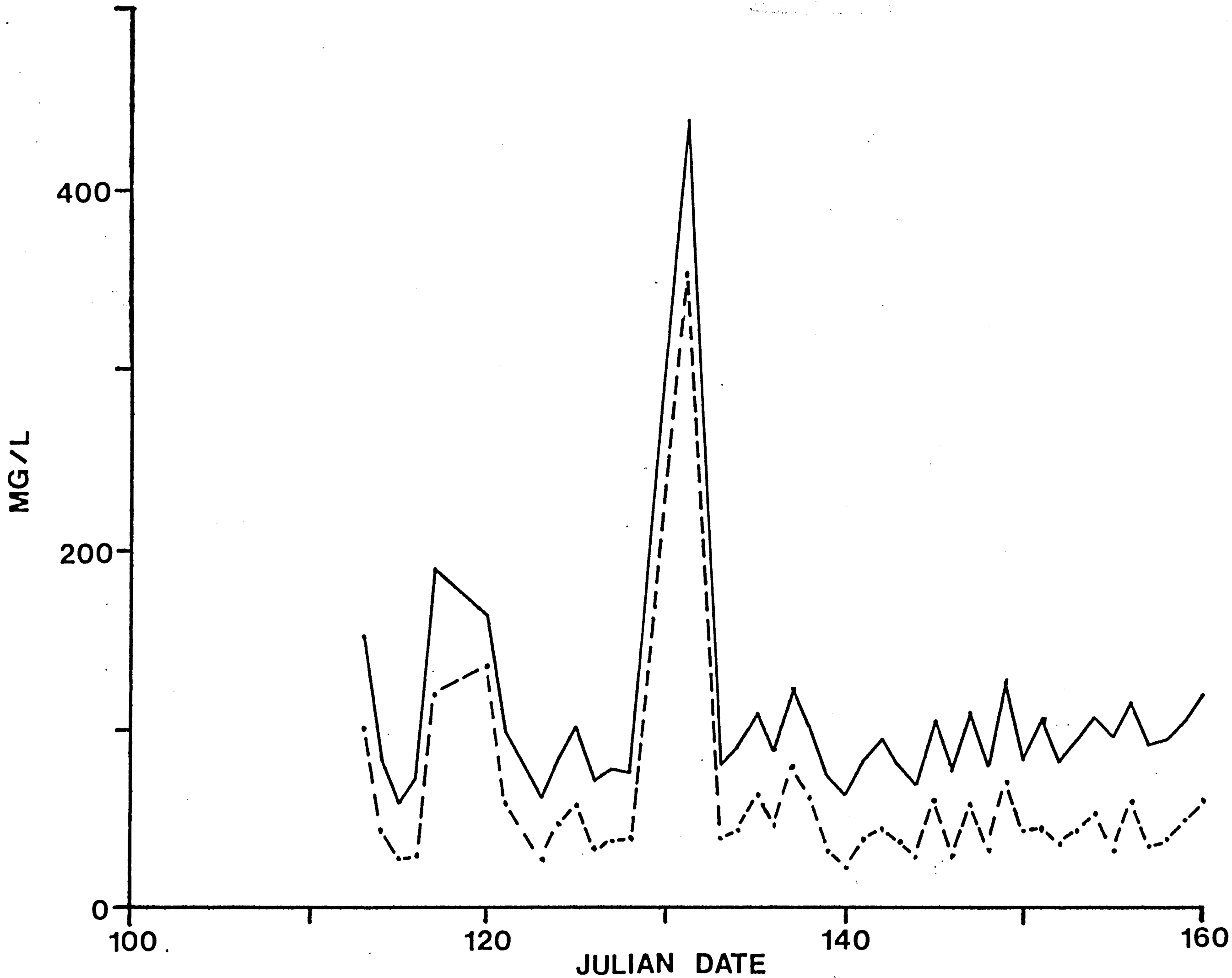


Figure 21. Particulate matter at PST1; April-June, 1974.

erodes more rapidly than clay or sand.

Sediment loads exceeding 5 g/l were recorded for runoff from the freshly-installed fire break in 1973, but such dramatic erosion was limited to steep slopes, and runoff rarely reached Squaw Lake.

Sediment loads in the four streams that were sampled in 1975 were quite comparable (see Figure 22). As at PST1 in 1974, sediment transport increased with increasing discharge. Values for PST1 in late April exceeded 150 mg/l when discharge exceeded 2.0 cfs but did not approach the high values of May 11, 1974.

3.) Gould Creek. Discharge data for Gould Creek have already been discussed. Water-quality parameters were similar to those measured in the epilimnion of Squaw Lake. Total phosphorus concentrations were typically lower than in the streams (5-25 μg/l), and conductivity was higher (100-150 $\mu mho/cm^2$). Particulate matter concentrations in Gould Creek were 100-125 mg/l in April and May, 1975. Because discharge from Squaw Lake exceeded input during much of the year it seems likely that significant amounts of P and dissolved solids were transported from the lake. It is less likely, however, that inputs of particulate inorganic matter remained suspended long enough to be transported to the north end of the lake and discharged via Gould Creek.

4. Lakes. The sampling of Squaw Lake had two objectives. First, it was hoped that any changes in the lake's characteristics resulting from the proposed treatments would be detected. Second, the sampling was designed to provide a characterization that would

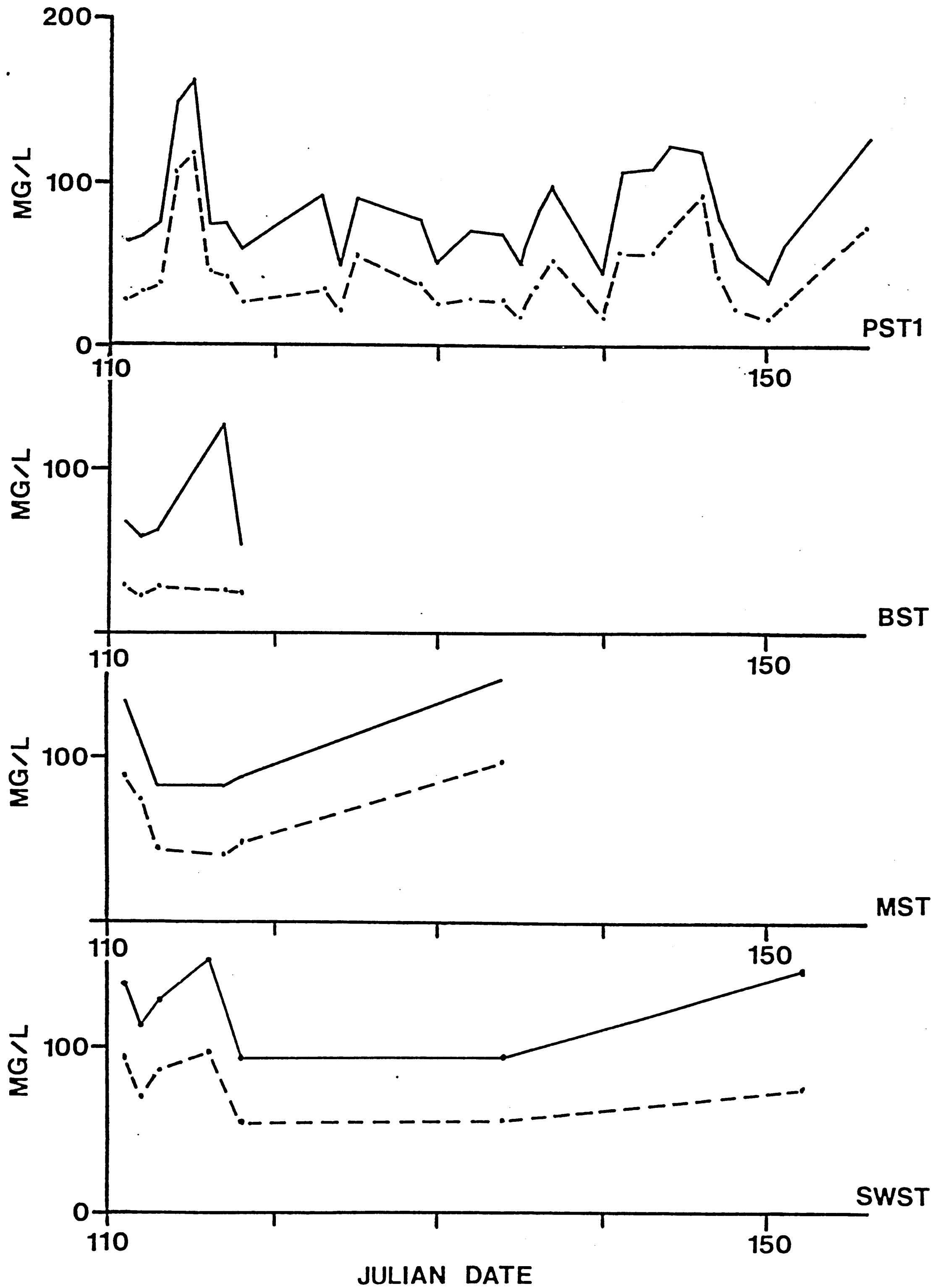


Figure 22. Particulate matter in streams sampled in 1975.

aid in the interpretation of the sediment cores. Myrtle Lake and the two ponds were sampled primarily to obtain a more complete characterization of the watershed's aquatic ecosystems. The sampling of the three smaller water bodies produced interesting results but are not dealt with in detail. The results of the Squaw Lake sampling are significant, and more emphasis will be placed upon them.

a. Regional comparisons. Table 27 summarizes selected parameters for several lakes in the Itasca area. Data are from Megard (1968) and several unpublished student reports on file at the Forestry and Biological Station. On the basis of the conductivity and alkalinity of its surface waters, Squaw Lake is more similar to small woodland lakes and ponds than to larger bodies of water. When combined with the results of the stream and groundwater sampling, the data in Table 27 support the argument that Squaw Lake is largely dependent upon surface runoff for its water. In general, Squaw Lake can be characterized as a brown, softwater lake. The other lakes in the area that are at least as large as Squaw Lake are blue, hardwater lakes. The unusual character of Squaw Lake's water is probably not related to land use history, since, for example, the watershed of Long Lake was logged at about the same time as Squaw Lake's (Vandersluis 1974).

b. Squaw Lake.

1.) Physical characteristics. Figure 1 shows several cross sectional profiles for Squaw Lake. The areas of all depth contours were determined with a planimeter, and the volume of Squaw Lake was

Table 27. Parameters for Itasca area lakes.

Lake	Surface Area (ha)	Conductivity (μmho/cm^2)	Total Alkalinity (meq/l)	Elevation (m)
Itasca	436	257(3)	3.29(7)	447
George	331	------	2.84	---
Island	221 (approx.)	550	3.6	---
Elk	101	234	3.08	448
Long	66.5	272	3.15(2)	---
Mary	23	------	2.28	456
Pond North	5.3	41(17)	------	501
Deming	5.1	55(3)	.55(3)	464
Josephine	5 (approx.)	57	.7	464
Myrtle	4.6	97(17)	------	495
Squaw Creek Pond	4 (approx.)	------	1.43	472
East Twin	3.6	------	2.32	460
Pond South	2.3	40(18)	------	500
Spencer	1.3	70	.77(2)	---
West Twin	1.2	------	2.24	460
Pond II	1 (approx.)	58	.34	471

Note: ( ) indicate reported values are averages of (N) samples.

calculated using the equation of Hutchinson (1975, p. 166). The total volume of Squaw Lake is 4,633,445 m^3. The typical summer epilimnion (upper 4.57 m) comprises 47.2 percent of the total volume. The lake has 2.7 miles (4.35 km) of shore line.

Perhaps the most striking feature of Squaw Lake is the degree to which its water levels change in response to spring runoff. Water levels for the period March 1973 to June 1975 are shown in Figure 23. During this two-year period levels fluctuated through a range of nearly 1.5 m. There was little lake-level response to spring runoff in 1973, but in 1974 and 1975 levels rose sharply. Peak runoff generally occurred at the time when ice was going out of the lake, and much of the over-winter increases shown in Figure 23 occurred in the spring just prior to ice-out. No data are available for these times, because water levels were difficult to measure. Flow through Gould Creek was occasionally impeded by the dam-building activities of beaver, but the water balance for April 1975 (when flow through Gould Creek was unimpeded) shows that inputs exceeded output during peak-flow periods.

After spring runoff, water levels dropped almost as rapidly as they had formerly risen. Between mid May and mid June, 1974 nearly 10 percent of the the total volume of Squaw Lake passed through Gould Creek. Ignoring groundwater losses, calculated hydrologic replacement times for Squaw Lake are .51 and 5.2 years when Gould Creek discharges are 10 and 1 cfs respectively. When Squaw Lake abandons its outlet, replacement time depends on groundwater losses and is

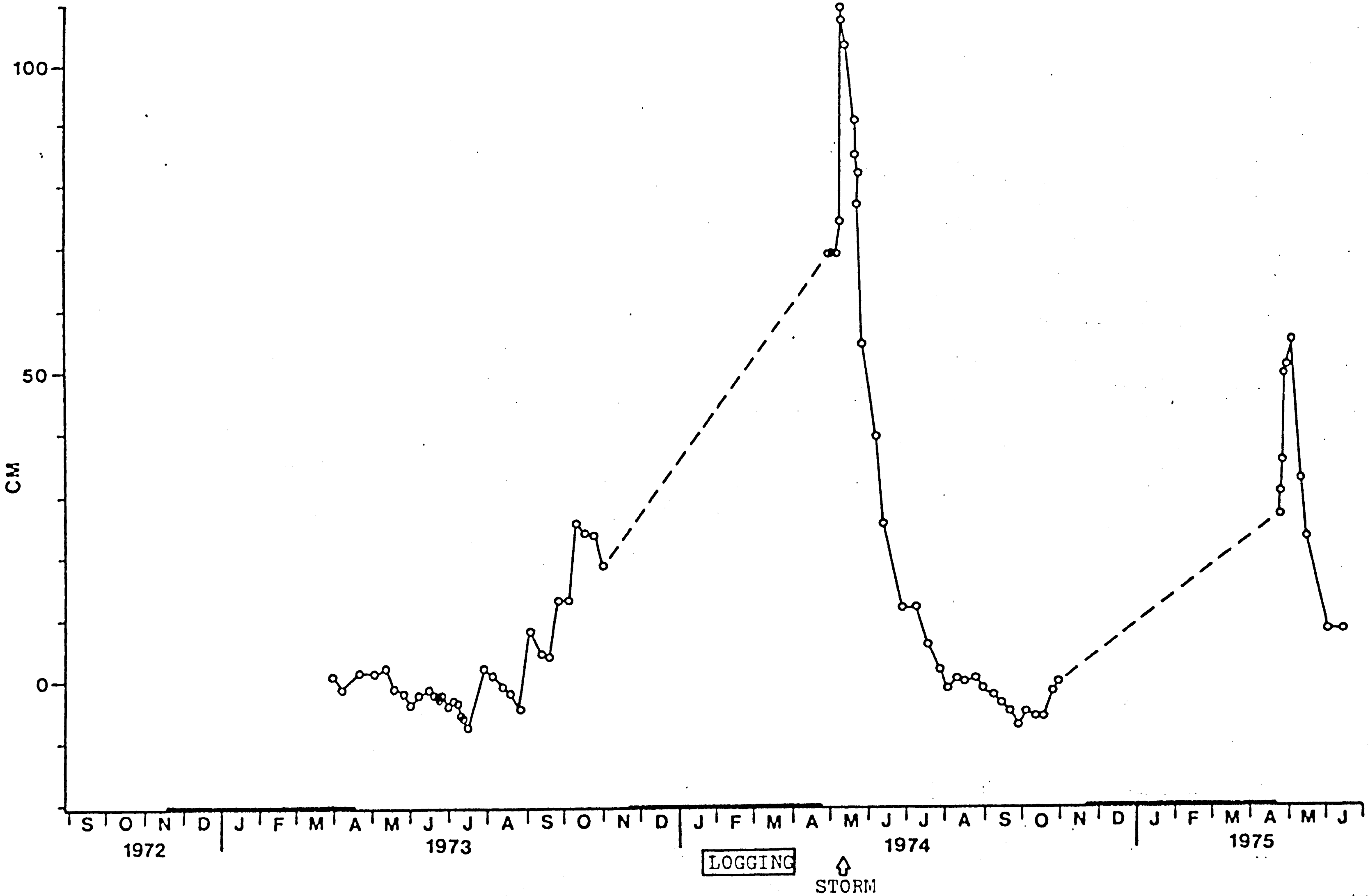


Figure 23. Water level changes for Squaw Lake, 1973-1975.

probably many tens of years.

In 1974 the May 10-11 storm resulted in a significant increase in Squaw Lake's water level. It rose nearly .5 m in a 3-4 day period, with much of the increase occurring on May 11. A beaver dam west of the park on SWST was blown out by state forestry personnel on this date. State employees estimated that Squaw Lake rose 4 in (10 cm) in one hour following the draining of a 20 acre (8.1 ha) pond. Discharges for all streams feeding Squaw Lake were probably greater on May 11, 1974 than at any time during the study. This is especially true for SWST where evidence of very high water levels was observed.

There is historical evidence indicating that Squaw Lake's water levels have fluctuated to an even greater extent in the past. Aerial photographs taken in 1939 and 1975 are shown on Plate 4. In 1939 the deep hole SE of the island was separated from the rest of the lake. Water levels rose during the 1940's, and by 1950 the island was surrounded by water. In 1975 the area shown as dry land in the 1939 photo was covered by at least 1.2 m of water. The evidence suggests that little water left Squaw Lake via Gould Creek during much of the 1930's.

Seasonal isotherms for Squaw Lake are presented in Figure 24. Data summarized are for the period September 1973-February 1975. Squaw Lake is generally isothermal at 4-5°C in both the fall and spring. Maximum water temperatures were 23-24°C during mid July in both 1973 and 1974. The hypolimnion was about 1°C warmer in 1973 than 1974, and the thermocline was 1-2 m shallower. Secchi disc

Plate 4. Aerial photographs of the Squaw Lake area taken in 1939 (a) and 1975 (b). Scale is 1:21120.

b.
a.

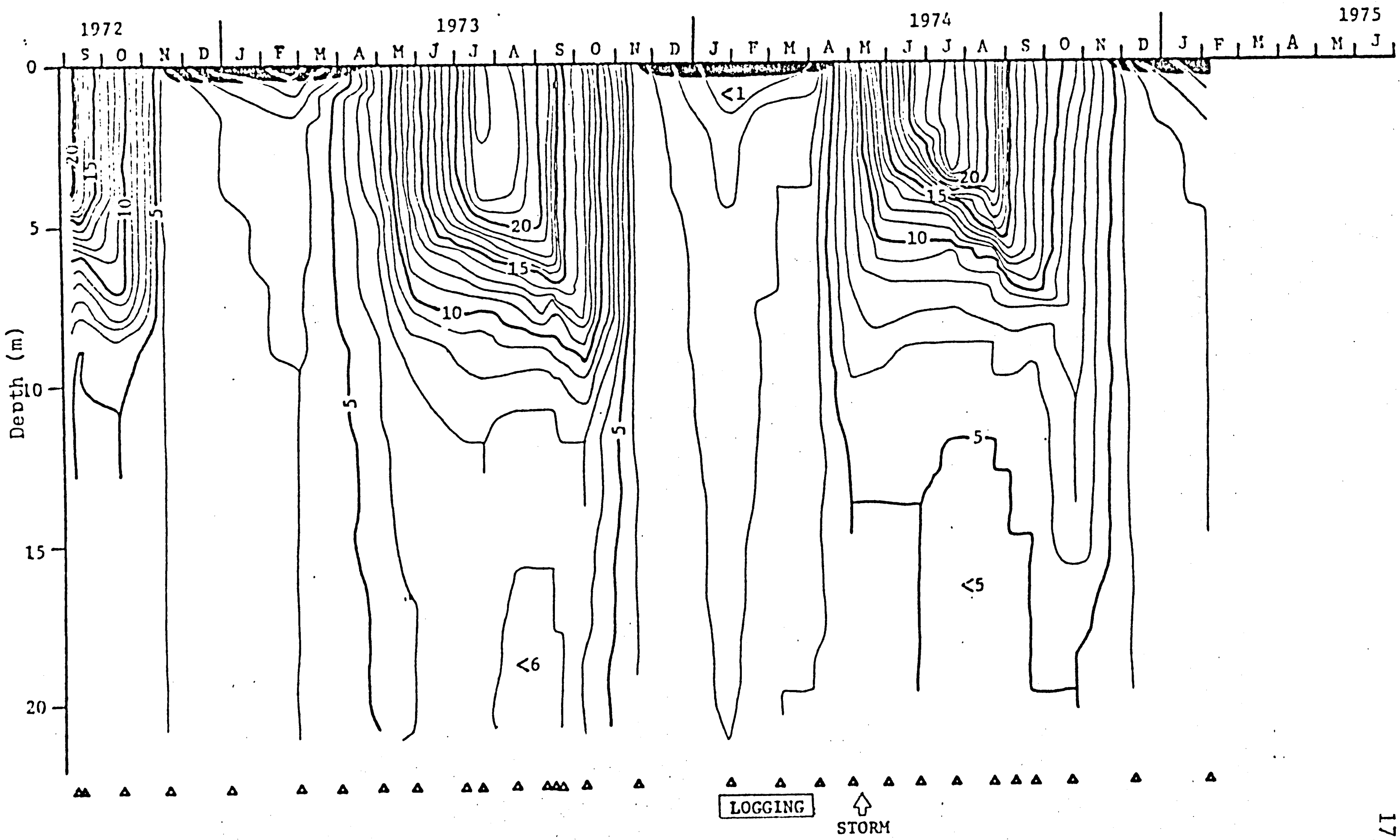


Figure 24. Seasonal isotherms (in °C) for Squaw Lake. ▲ indicates sampling date.

readings (Figure 25) show that Squaw Lake's surface waters were less transparent in May 1974 than at any other time during the study. The May 16 value of 3.51 m is .54 m lower than any other Secchi reading obtained for Squaw Lake. The reduced transparency probably was the result of increases in suspended particulate matter carried into the lake during the May 10-11 storm. Particulate matter concentrations were not determined for Squaw Lake until June 1, however. By that time transparency had increased to 4.54 m, and total particulate matter concentrations were only slightly elevated (1.2-1.4 mg/l vs. .9-1.2 mg/l for comparable 1973 data). The results of the June 1, 1974 sampling suggest that there is rapid settling of particulate matter carried to the lake during spring runoff.

2.) Chemical characteristics. For a given sampling date, variations in chemical parameters were observed both vertically within the water column and horizontally for the four surface-sample sites. Temporal variations were also observed. Vertical, horizontal, and temporal variations for all chemical parameters are summarized in Figures 26-35.

Squaw Lake had an orthograde oxygen curve only during fall turnover in 1972 and 1973. Partial turnover occurred during spring and fall, 1974. The incomplete turnover during the spring of 1974 may have been caused in part by the heavy runoff associated with the May 10-11 storm. The high water levels and large amounts of suspended particulate matter may have caused the lake's surface water to heat more rapidly than in 1973. Mixing of the water column is

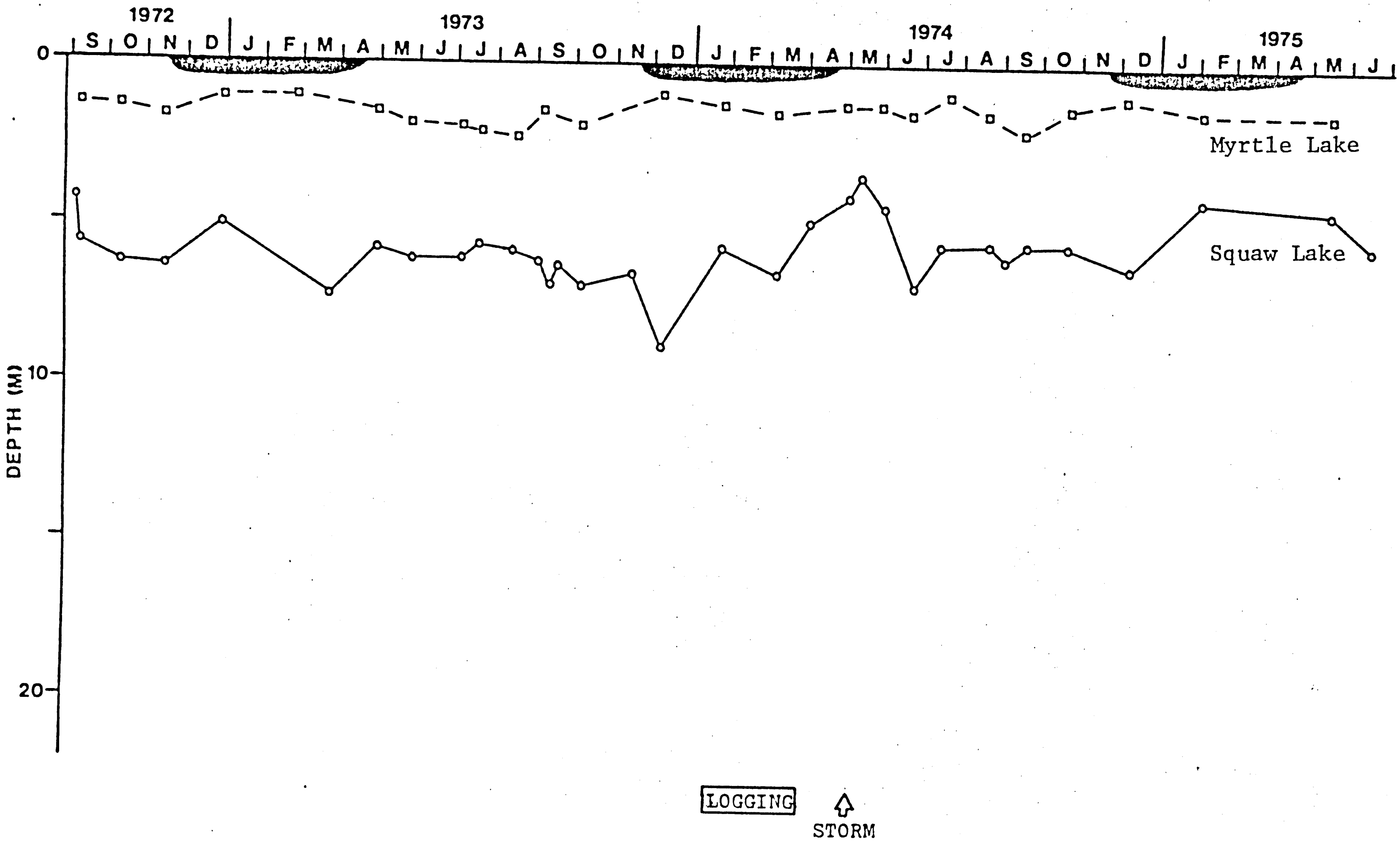


Figure 25. Secchi readings for Myrtle and Squaw Lakes.

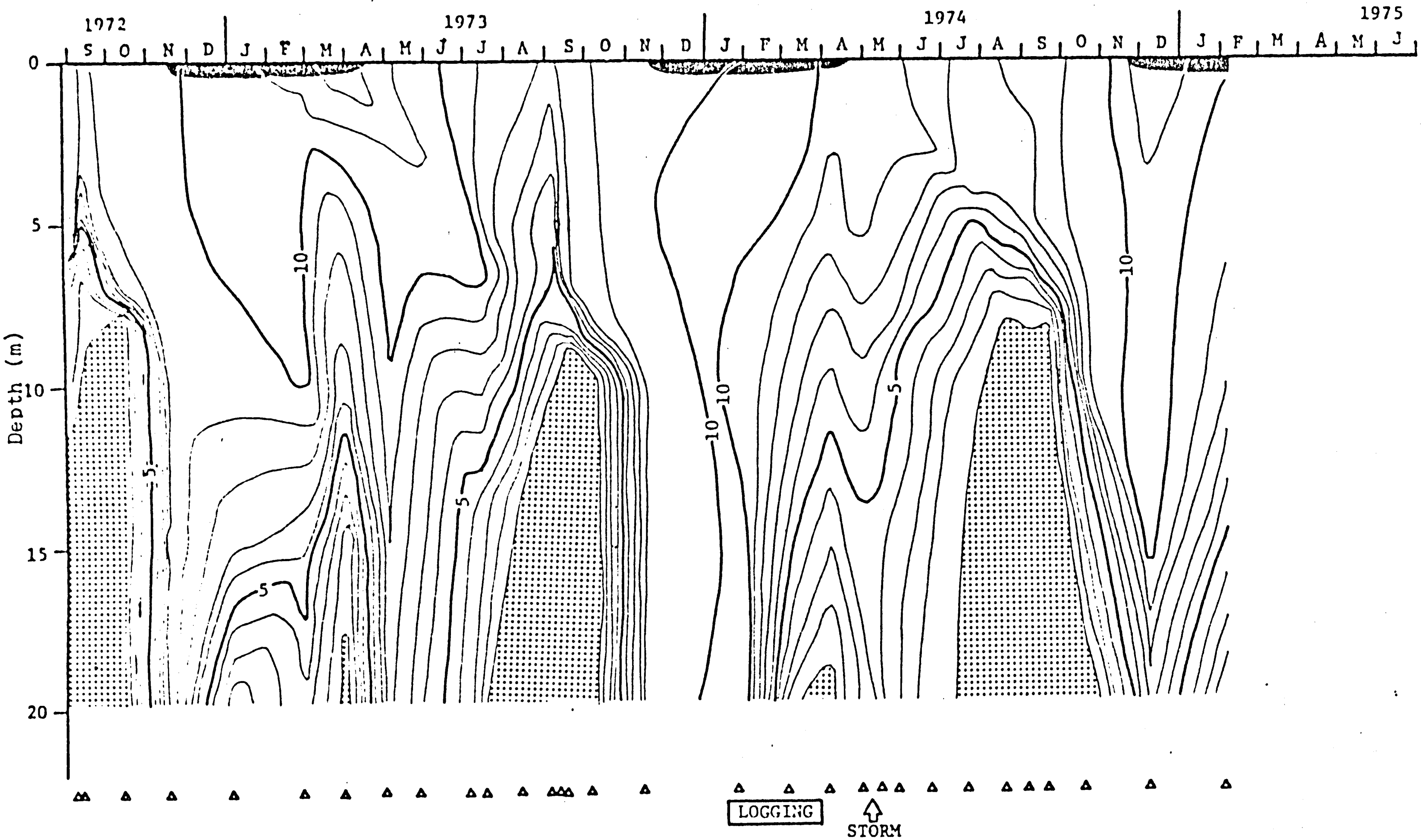


Figure 26. Seasonal isopleths for dissolved oxygen (in mg/1) for Squaw Lake. Stiples indicate <1 mg/1. △ indicates sampling date.

only possible when surface waters remain relatively cool. More of the hypolimnion was anoxic in 1974 than in 1973, probably because of the incomplete spring mixing.

Dissolved oxygen concentrations for Squaw Lake's surface waters (Figure 27) varied inversely with temperature. This is to be expected, because cold water has a greater capacity to retain oxygen than warm water. Generally samples for a given date were comparable when the lake surface was free of ice. Under ice cover, variability was greater but was apparently not related to location. In 1973-74, the pelagic sample (SLO) was generally lower than the littoral samples, whereas the reverse was true in 1974-75.

Phosphorus was sampled more intensively than other elements. Recent studies have demonstrated the importance of P to lake productivity. Shindler (1974) used whole-lake fertilization experiments to show that P rather than N or C limits productivity in lakes of the Canadian shield. A symposium held in 1971 by the American Society of Limnology and Oceanography examined the role of different nutrients in the eutrophication process (A.S.L.O. 1972). in a panel discussion at the end of the sumposium, A.F. Bartsch asked the question "What in the world should be removed" from eutrophic lakes and answered with the statement, "For the many reasons already pointed out at this meeting, the answer is phosphorus." At least for culturally eutrophic lakes, it is generally conceded that P is the nutrient that limits productivity.

Isopleths of total P (TP) for the Squaw Lake water column are found on Figure 28. Epilimnetic concentrations of TP never ex-

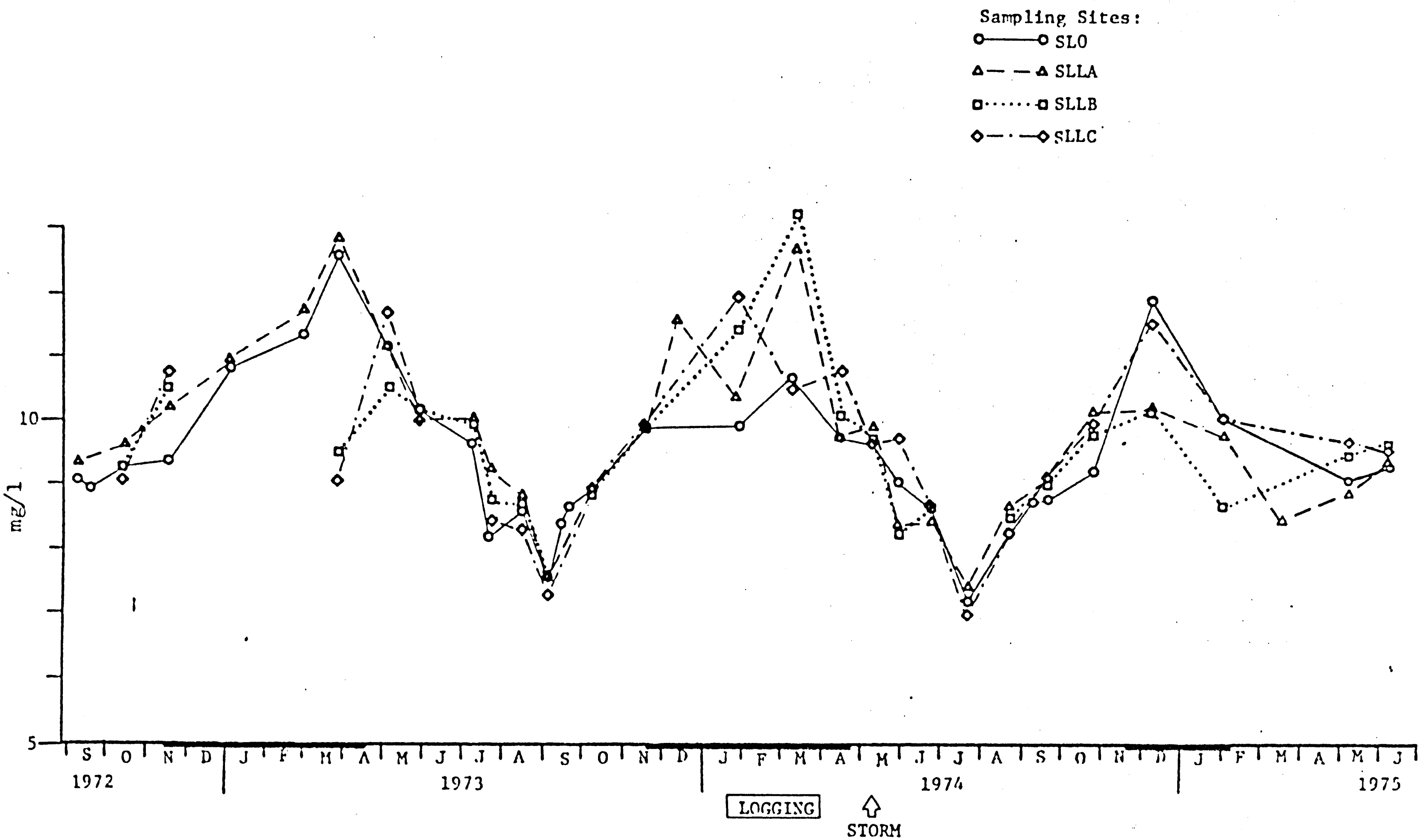


Figure 27. Dissolved oxygen at Squaw Lake surface sampling sites.

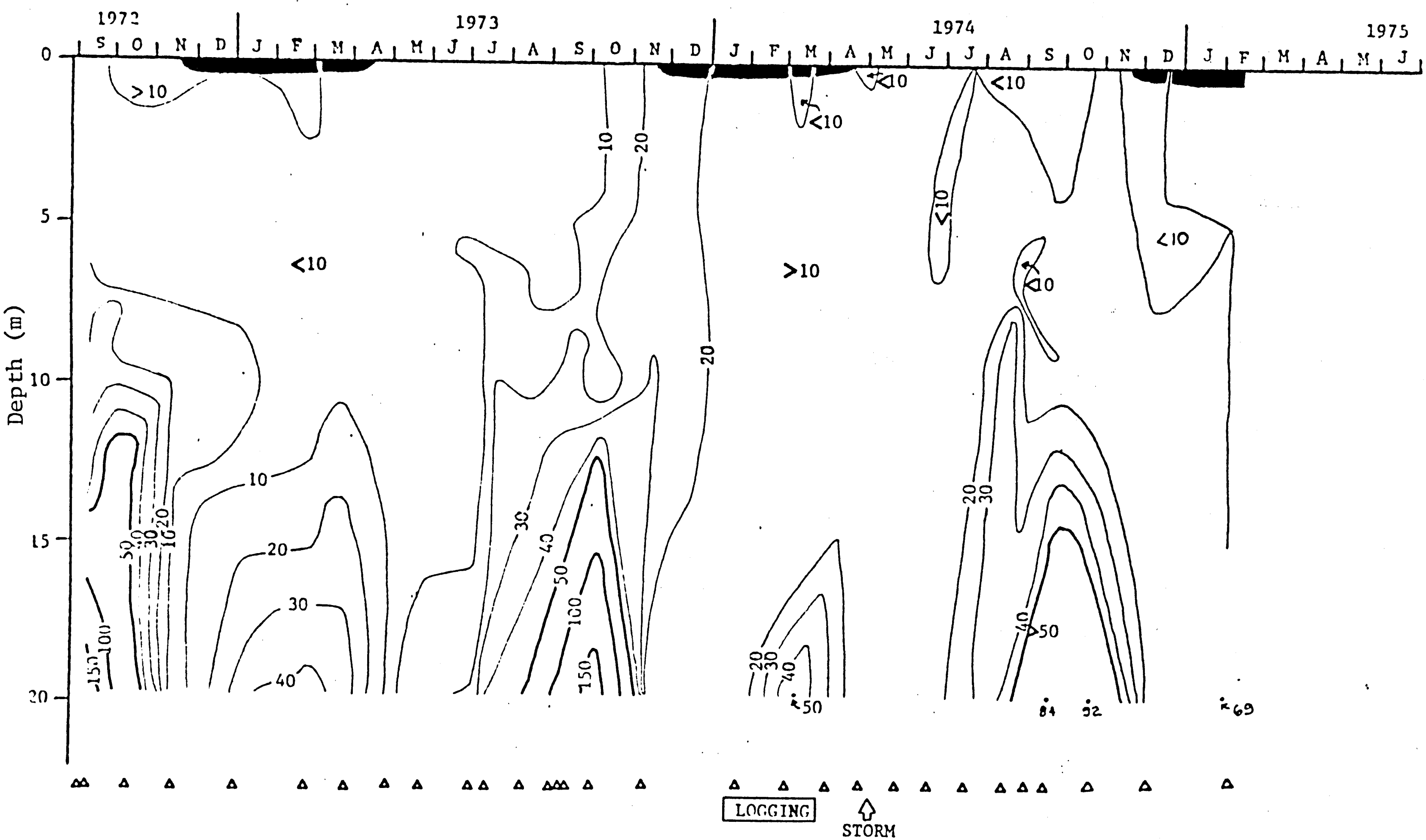


Figure 28. Seasonal isopleths for total phosphorus (in μg/1) for Squaw Lake. Δ indicates sampling date.

ceeded 20 μg/l. When the surface of the lake was covered with ice, however, concentrations of phosphorus in surface waters increased (Figure 29). Highest concentrations generally occurred near shore in late winter. The importance of these increases to algal productivity will be discussed in conjunction with the chlorophyll data.

Isopleths for iron are presented in Figure 30. In Squaw Lake Fe and TP concentrations are significantly correlated (r = .94). Hypolimnetic phosphorus and iron increase dramatically as oxygen concentrations fall. Under anoxic reducing conditions Fe remains in solution as Fe^{++}. In the presence of oxygen, however, these ions are oxidized, and insoluble ferric hydroxide and ferric phosphate precipitates are formed (Ruttner 1972). The importance of precipitating Fe and P to sedimentary concentrations of these elements has already been discussed.

Nitrate concentrations in Squaw Lake (Figures 31 and 32) show patterns similar to those for TP. The late-winter increases in nitrate concentrations at the littoral sampling stations occurred at the same time that concentrations of NO_3^- in water trickling through the flume were high. This suggests that NO_3^- may be entering the lake via subsurface groundwater flow. Alternatively, increases may be related to nitrate release from decomposing organic matter on the lake floor. Substantial amounts of leaves and dead macrophytes collect in the littoral region and decomposition over the winter could ultimately lead to nitrate release in the spring. To few data were collected at Squaw Lake to examine these hypotheses.

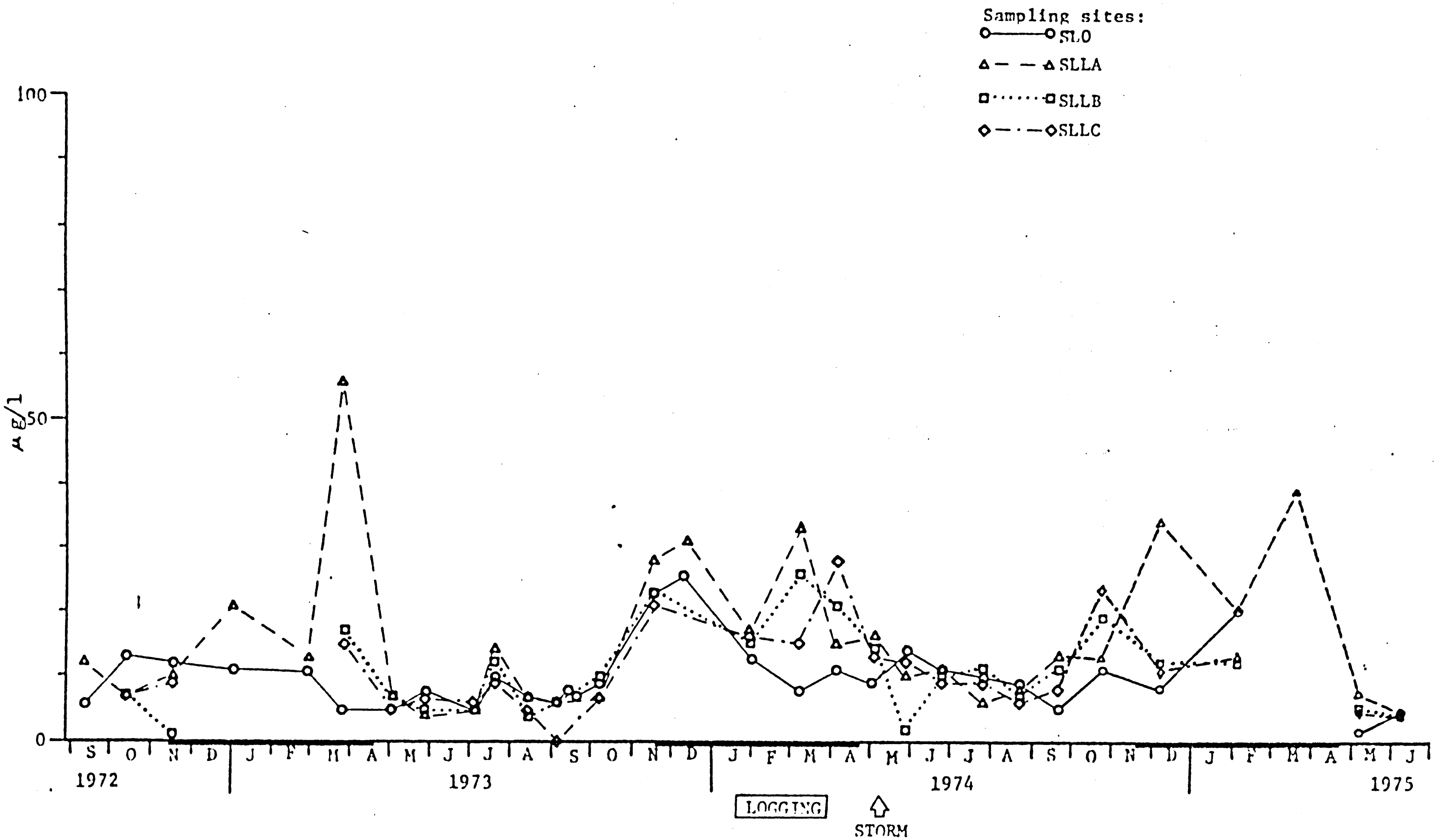


Figure 29. Total phosphorus at Squaw Lake surface sampling sites.

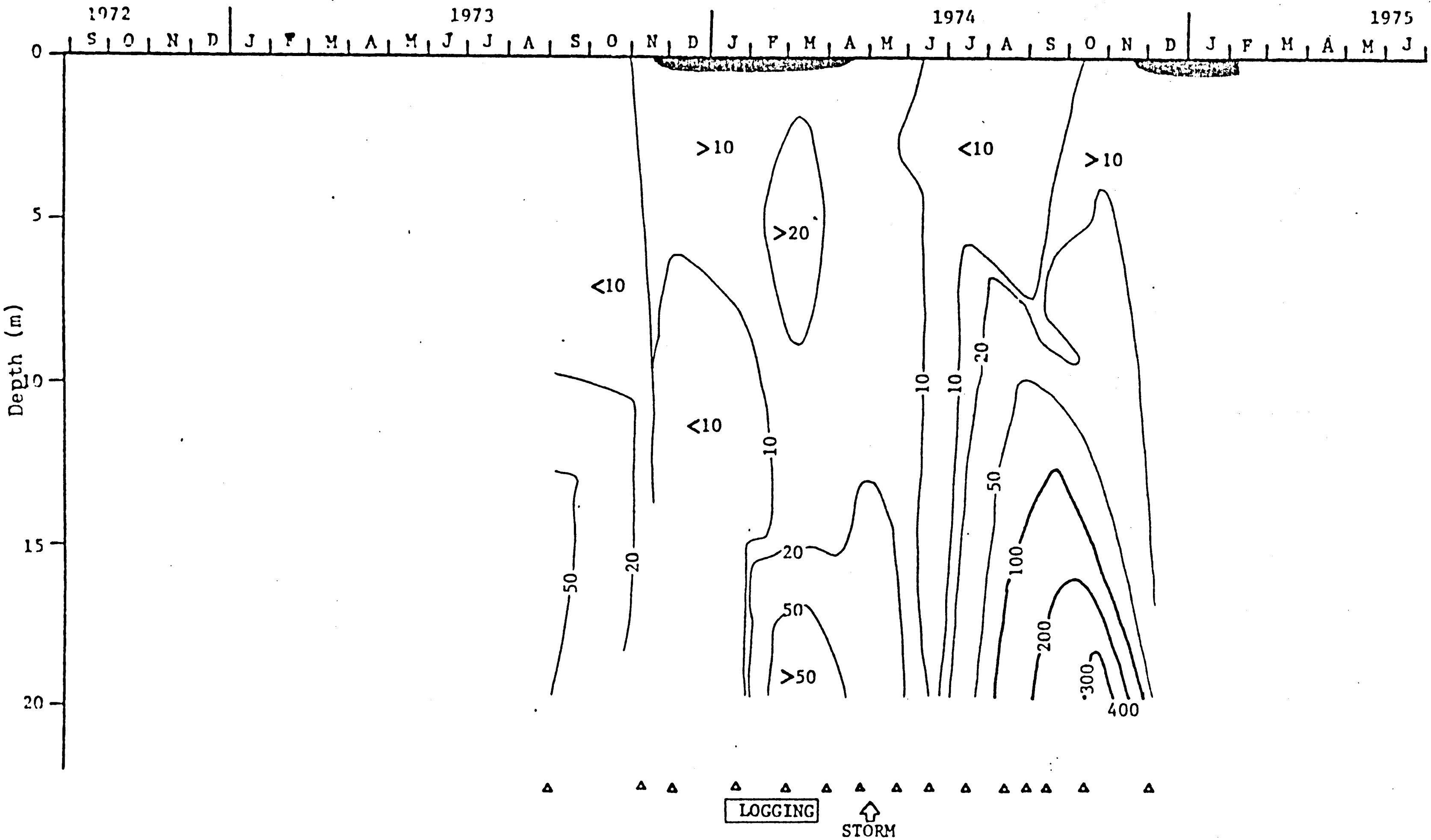


Figure 30. Seasonal isopleths for iron (in mg/l) for Squaw Lake. ▵ indicates sampleing date.

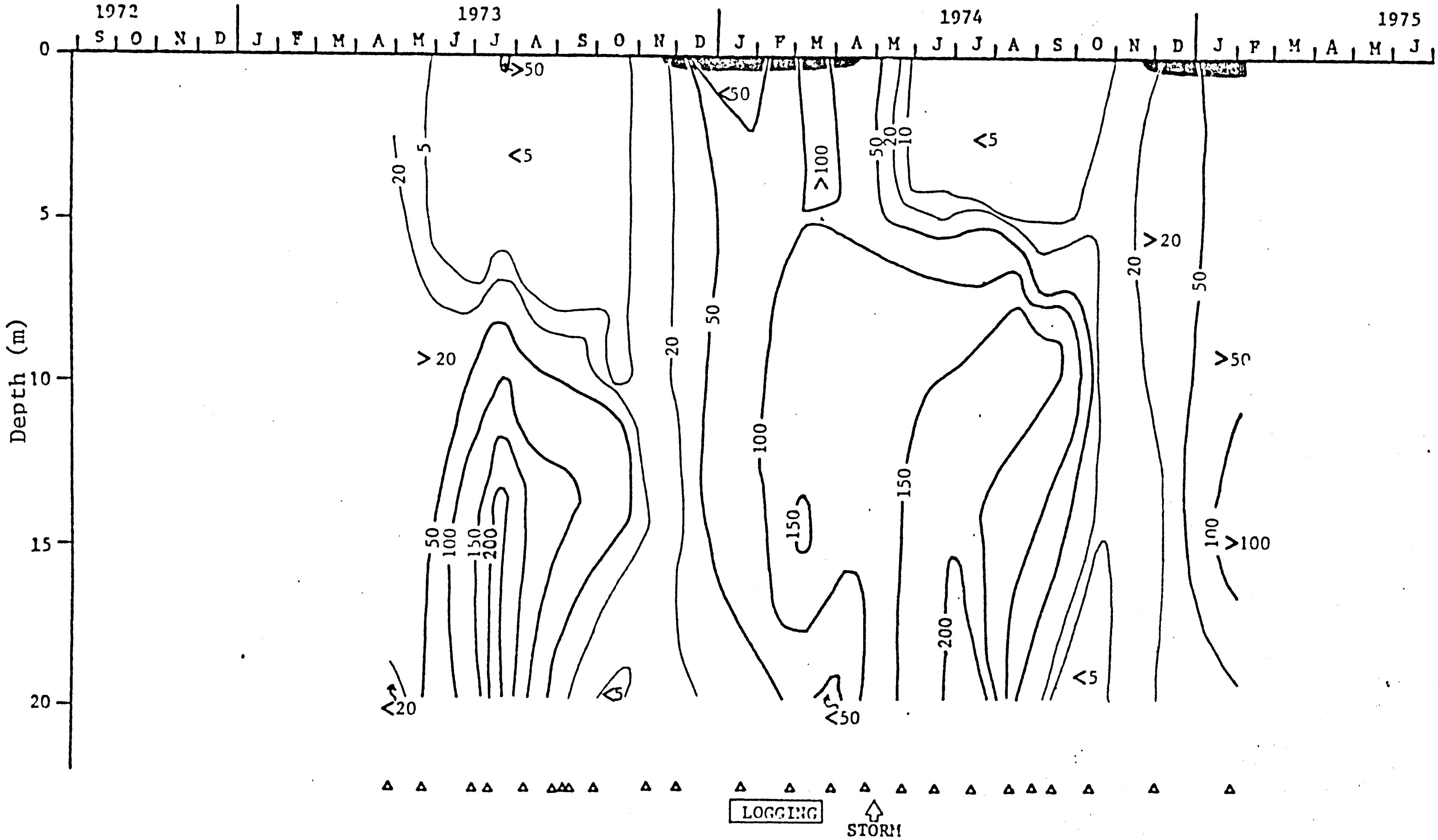


Figure 31. Seasonal isopleths for nitrate (in μg/l) for Squaw Lake. Δ indicates sampling date.

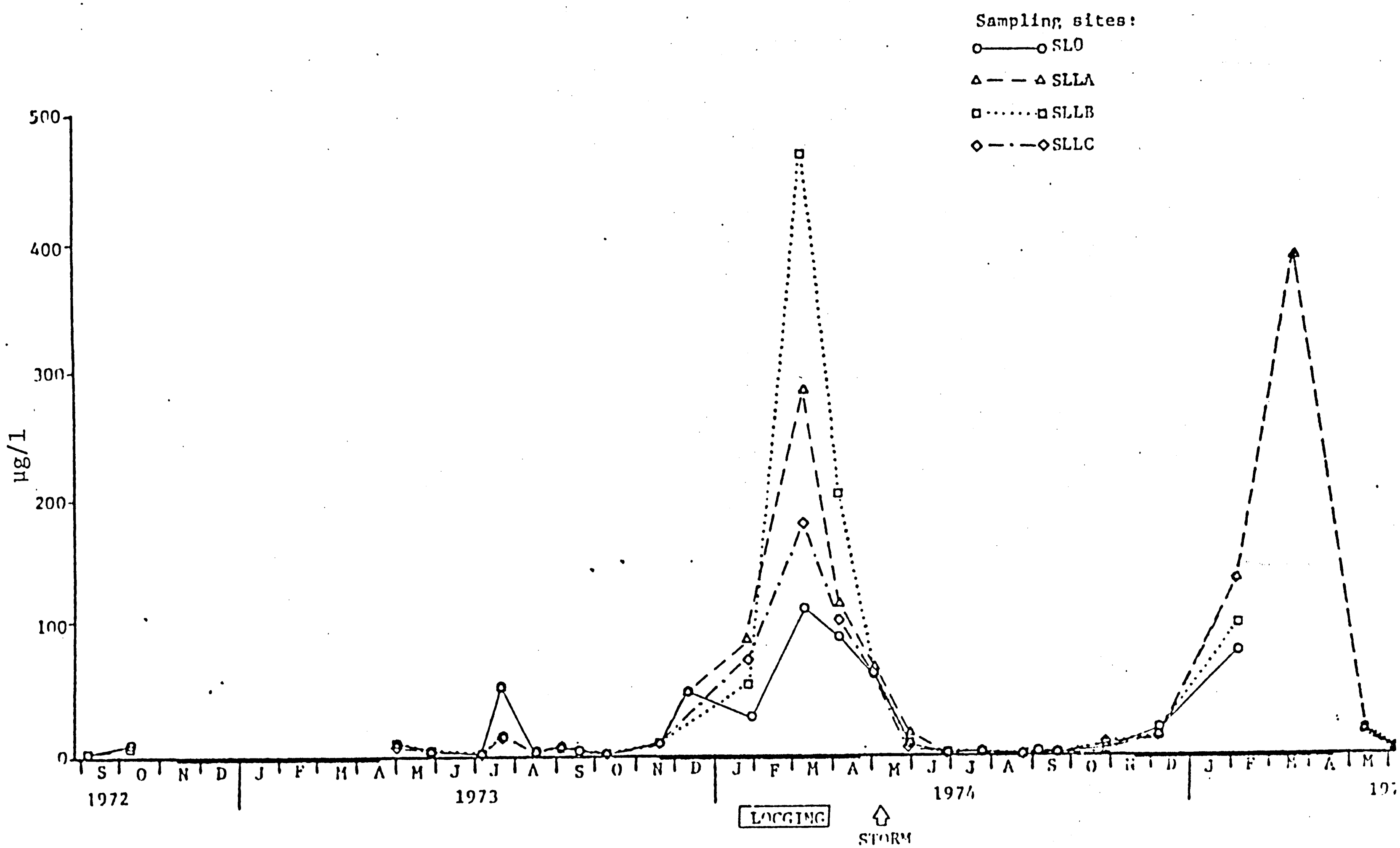


Figure 32. Nitrate at Squaw Lake surface sampling sites.

Ammonium was sampled only three times. Values generally were highest (.2-.9 mg/l) in the hypolimnion and lowest (<.1 mg/l) in the epilimnion. Concentrations of total Kjeldahl N varied temporally with respect to both depth and sampling station. Concentrations were lowest (.2-.3 mg/l) during the winter. The highest concentrations (>1.5 mg/l) occurred in hypolimnetic waters during August, 1973. For the euphotic zone, summer concentrations were typically >.75 mg/l in 1973 and <.65 mg/l in 1974.

Concentrations of Ca^{++} and Mg^{++} were determined on five occasions. Ranges are shown in Table 28. Also included are data for other Itasca area lakes as determined by Megard (1968). Conductivities in Squaw Lake were significantly correlated with Ca^{++} plus MG^{++} ($r = .87$). During thermal stratification, hypolimnetic waters had conductivities that were 20-30 units higher than in surface water. Surface-water conductivities are plotted on Figure 33. They increased slightly during mid winter, perhaps as a result of the concentration of ions by the freezing of surface waters. Also, groundwater influences may be greater during the winter months when inputs from surface runoff and precipitation cease. The high conductivities at SLLA and SLLB in March, 1973 correspond to increases in other chemical parameters and suggest that groundwater inputs may be responsible for these near-shore variations.

3.) Biological characteristics. Chlorophyll data are plotted on Figures 34 and 35. Epilimnetic blooms occurred in May of 1973 and 1974. Although data are not graphed, a bloom also was observed in

Table 28. Calcium and magnesium concentrations for selected Itasca area lakes (after Megard 1968) and Squaw Lake (this study).

Lake	Date	Ca^{++} mg/l	Mg^{++} mg/l
Squaw	Oct. 72	11.0-16.5[1]	3.3-4.9
Squaw	May 73	7.7-14.6	1.1-5.5
Squaw	Jan. 74	10.0-17.4	2.1-5.3
Squaw	June 74	16.1-18.8	5.0-5.7
Squaw	Sept. 74	17.0-20.6	5.2-5.8
Itasca	--------	38.1	15.3
Elk	--------	38.4	11.7
Long	--------	33.6	18.5
Mary	--------	37.4	11.1

[1]Values are the range within the water column.

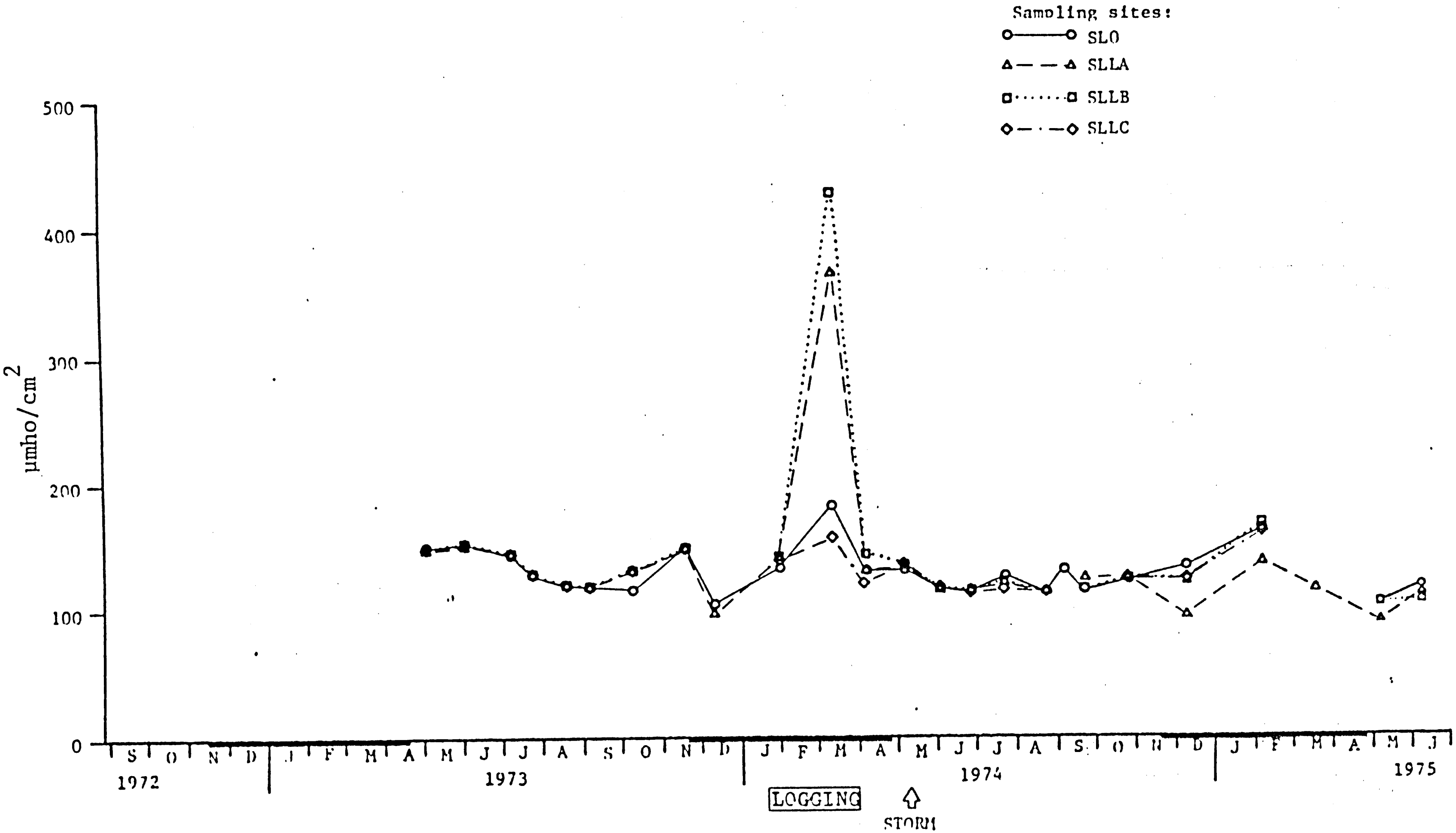


Figure 33. Specific conductance at Squaw Lake surface sampling sites.

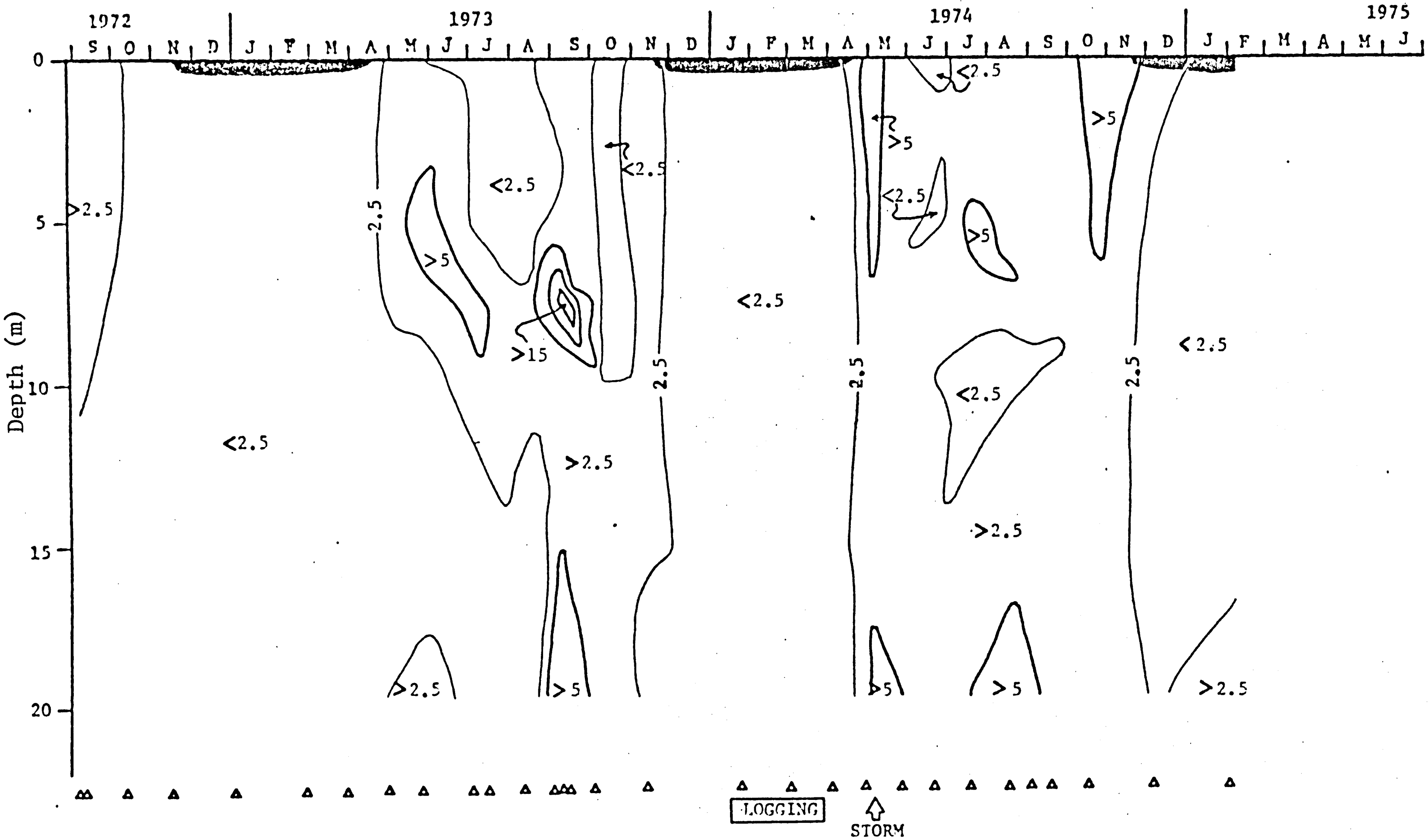


Figure 34. Seasonal isopleths for chlorophyll a (in mg/m^3) for Squaw Lake. ▵ indicates sampling date.

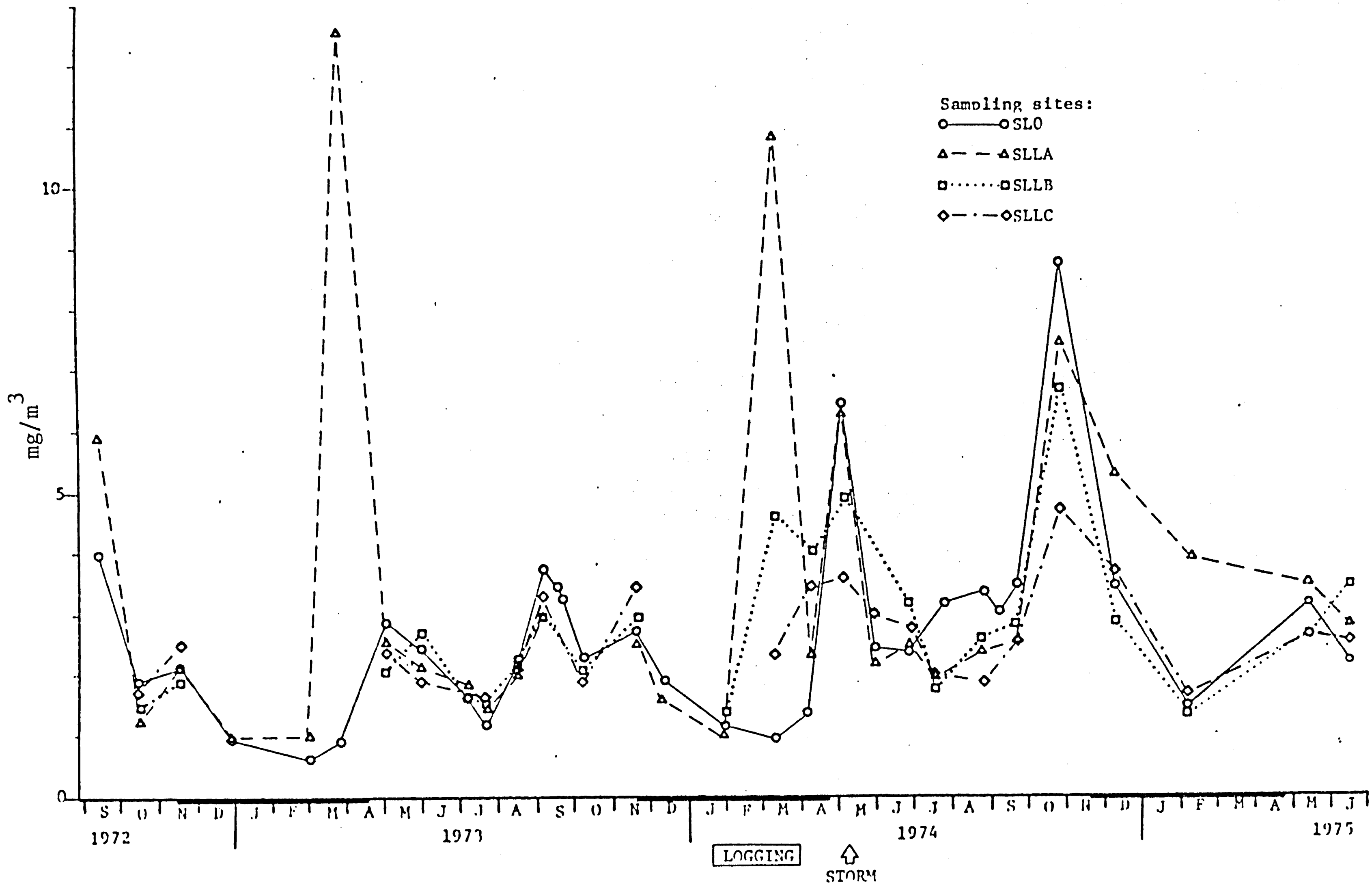


Figure 35. Chlorophyll a concentrations at Squaw Lake surface sampling sites.

May, 1975. Spring blooms of diatoms and green algae are typical in Minnesota lakes and apparently occur in response to increased nutrient availability following spring runoff. In 1973 and 1975 chlorophyll concentrations were greatest at 5 m where they exceeded 5.0 µg/l. In 1974 concentrations were greatest at the surface. Although sampling in the spring was accomplished only at four week intervals, the 1974 bloom appeared to occur somewhat earlier than the 1973 and 1975 blooms. A maximum value of 6.46 µg/l. was recorded for Squaw Lake surface waters on May 4, 1974. Thus the bloom began before the May 10-11 storm. By June 1, 1974 chlorophyll concentrations at the surface had fallen to <2.5 µg/l.

In addition to the spring blooms, metalimnetic algal blooms occurred in 1973 and 1974. The 1973 bloom was much more intense than that in 1974. Chlorophyll concentrations exceeded 19.0 µg/l at 8 m on September 12, 1973, whereas in 1974 they did not exceed 6.5 µg/l. The bloom in 1974 began nearly a month earlier than that in 1973, however, and it is possible that the peak of the bloom was not sampled.

The factors causing these late-summer blooms are not known, but they may occur in response to a downward shift in the thermocline. during both 1973 and 1974 the thermocline dropped at about the time the blooms began. In both years chlorophyll concentrations were highest at the base of the metalimnion. Just below this level dissolved oxygen concentrations dropped, and concentrations of NO_3^- increased 3-4 fold. Concentrations of TP were also elevated in the hypolimnion in late summer. Total P did not, however, increase with increasing chlorophyll concentrations. Normally one would expect a high correlation between chlorophyll and TP if P is limiting productivity. The lack of such a relationship in Squaw Lake may be explained by the algal species responsible for the bloom. Blue green algae were observed in the Squaw Lake samples, and Shapiro (1973) has shown that these algae are capable of producing blooms in the absence of large amounts of phosphorus.

The 1973 late-summer-bloom was sampled on the 3rd, 12th, and 19th of September. On the first two dates maximum chlorophyll concentrations were at 8 m and were 2-4 times those of pheopigments. By September 19, however, chlorophyll was highest at 9 m, and pheopigment concentrations were twice those of chlorophyll. A low chlorophyll: pheopigment ratio indicates a senescent algal population, and at Squaw Lake the late-summer bloom apparently declines in response to decreased light availability. As the thermocline deepens during the fall, algae flourish as long as they remain in contact with nutrient-rich hypolimnetic waters. Eventually, however, the base of the thermocline drops below 8 m (the 1 percent light compensation level for Squaw Lake), and low light levels limit photosynthesis.

A late-autumn algal bloom occurred in Squaw Lake in 1974, but it was sampled only once, on October 29. Chlorophyll concentrations were highest at the surface, and light appeared to limit the bloom's vertical distribution. At the surface, chlorophyll concentrations were twice those of pheopigments, whereas at 5 m concentrations of pheopigments were three to four times those of chlorophyll.

The high hypolimnetic chlorophyll concentrations that occurred in conjunction with most blooms (see Figure 34) apparently represent dead or dying algae. Pheopigment concentrations were almost always higher than chlorophyll concentrations in the hypolimnion.

In 1973 and 1974, algal blooms were observed at SLLA during March. These blooms occurred under the ice at the time when TP, NO_3^- and conductivity were elevated. The blooms appeared to be limited to the area surrounding the mouth of PST. Similar blooms were not observed at the mouths of BST or MST. No water was flowing in these two streams at the time, and the results suggest that the bloom at SLLA occurred in response to the initial flow through PST. After ice-out, wave action apparently dispersed the bloom, for chlorophyll concentrations at SLLA were then similar to those at the other surface sampling sites.

c. Myrtle Lake. Myrtle Lake was meromictic during most of the study period. The bottom waters (8 m) of the lake had dissolved oxygen concentrations >1.0 mg/l only in November 1972. Even then mixing was incomplete and dissolved oxygen concentrations were 3.5 mg/l lower at 8 m than at the surface. Typically, dissolved oxygen was completely absent below 4-5 m except during the spring and fall. Myrtle Lake has highly colored waters, and Secchi readings (Figure 25) rarely exceed 2 m. Thermal gradients were very steep during summer months. In July 1973, for example, temperatures dropped 9°C between 1.5 and 3.0 m. In July 1974 temperatures dropped 11°C between the same depths. Chemical stratification was even more pronounced. Dissolved oxygen concentrations at the surface were 8.4 mg/l in July, 1974, whereas at 1.5 m concentrations were only 1.0 mg/l. During the summer, conductivities were 1.5-2.0 times greater at 8 m compared to the surface where values ranged from 70-90 μmho/cm^2.

Light penetration into Myrtle Lake was restricted during the summer months by dense algal blooms. Chlorophyll concentrations in excess of 90 μg/l were measured at 2 m on August 17, 1973. On September 23, 1974 a maximum value of 113 μg/l was recorded at 4 m. Only during January and February were concentrations lower than 10 μg/l, and it was not uncommon for chlorophyll concentrations to exceed 10-20 μg/l. Surface concentrations were higher than those for the metalimnion in early spring and late fall, and the reverse was true during periods of thermal stratification. Concentrations of suspended particulate matter were 4-6 mg/l when chlorophyll concentrations were highest. These values are 3-4 times higher than Squaw Lake values for comparable sampling dates. The greater productivity of Myrtle Lake probably is largely responsible for the greater sediment accumulation rate.

Total phosphorus concentrations in Myrtle Lake's surface water varied seasonally between 20-80 μg/l. Hypolimnetic concentrations were generally much higher, however, and reached a maximum of 470 μg/l on August 24, 1974. Apparently TP is not retained in the sediments of Myrtle Lake, but rather remains in solution because of the strong reducing conditions in the hypolimnetic waters. Hypolimnetic concentrations of Fe usually were in excess of 2-4 mg/l during the summer months. The fact that the water column has little or no oxygen for much of the year probably prevents the precipitation of Fe and P. During periods of partial circulation Fe and P may be carried from Myrtle Lake via MST. Ultimately, they may be precipitated from the waters of Squaw Lake.

Kjeldahl N concentrations were usually 3-4 times higher in Myrtle Lake compared to Squaw Lake, whereas nitrate concentrations varied greatly during the year. Although exceptions occurred, there generally was an inverse relationship between nitrate concentrations and the concentrations of both chlorophyll and Kjeldahl N. This suggests that N may limit productivity in Myrtle Lake. Klemmer (1974) used fertilization experiments to demonstrate that N stimulates the productivity of Oscillatoria in Demming Lake--a small meromictic lake in the eastern portion of Itasca State Park.

d. The ponds. Pond North and Pond South were formed at the same time about 35 years ago when beaver dammed a portion of the PST drainageway. The 1939 air photo of the Squaw Lake area (Plate 4) shows both ponds as marshy areas with no open water. Several jack pine snags stood in the water of Pond South, and analysis of cores from these trees indicates that they died in the early 1940's. The dead jack pine germinated in the 1890's, and their survival until about 1942 indicates that the ponds were dry during the period 1890-1940. During the study period, water levels of both ponds fluctuated through .75-1.0 m (see Figure 36), and the ponds dried completely during the dry summer of 1976.

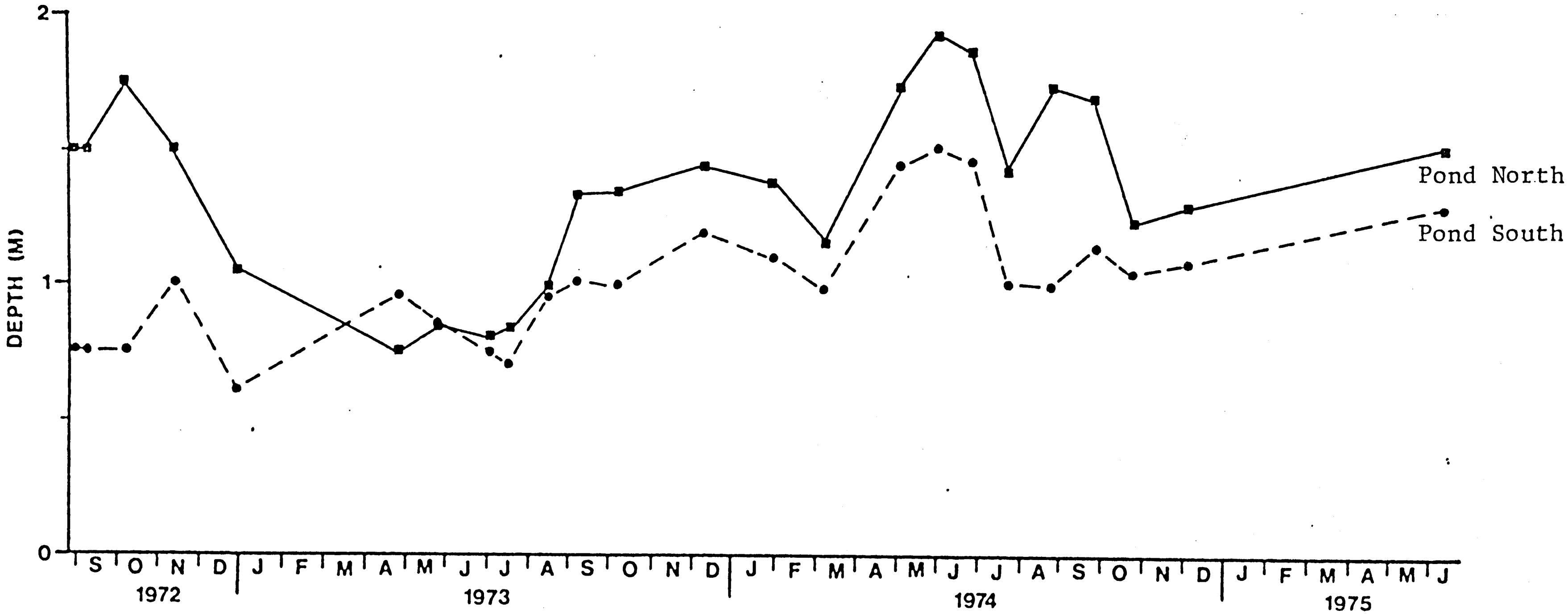


Figure 36. Water level fluctuations for Pond North and Pond South.

Transparency of the ponds' waters was similar to that of Myrtle Lake. Pond South appeared to have somewhat greater transparency, but water levels were never greater than 1.5 m. Secchi depths always exceeded this value. Secchi readings for Pond North, on the other hand, were frequently 1.0-1.5 m. Both ponds had orthograde temperature curves during the summer of 1973. During 1974 some stratification was observed in both ponds, but temperatures of the bottom water were always $>10^{\circ}C$, and it is unlikely that stratification persisted for more than a few days.

Chemical and biological parameters for the ponds were quite different from those for Myrtle and Squaw Lakes. Conductivities were generally very low (30-40 $\mu mho/cm^2$). Only during the winter months, when the ponds froze almost completely, did conductivities rise to 70-80 $\mu mho/cm^2$. Dissolved oxygen concentrations averaged about 5.0 mg/l during the summer. In the spring and the fall, when water temperatures were lower, concentrations increased to 8-10 mg/l. The water that remained under the ice in winter had very low concentrations of dissolved oxygen (1.0-1.5 mg/l).

Chlorophyll concentrations for Pond North were 25-30 µg/l in the spring of 1973 and 5-15 µg/l during most of 1974. Pond South usually had lower chlorophyll concentrations, but blooms did occur, especially under the ice in early winter. Concentrations of TP, NO_3^-, and Kjeldahl N were intermediate between Squaw Lake and Myrtle Lake values.

VI. DISCUSSION

A. The Origin of Sediment Bands in Squaw Lake

The presence of white sediment bands in Squaw Lake poses three questions: Of what are the bands composed? Where does the material in the bands come from? Is the formation of bands related to external factors such as terrestrial land disturbance? The results of this study provide answers to the first two questions and suggest an explanation for the third.

Microscopic examination of the sediments shows that bands are composed of inorganic particulate material. Individual particles are the size of silt and fine sand (2-100μ) and are not diatoms. Chemical analysis indicates that the sediments of Squaw Lake contain little $CaCO_3$ even within the bands. *A priori*, one would not expect to find marl deposits in lakes with soft water.

The silt and fine sand that make up the sediment bands are almost certainly carried to the lake by the streams that enter from the west and south. Aeolian transport can be discounted, for other lakes in the area do not have similar bands. Furthermore, the stream sampling clearly demonstrated that streams can carry large amounts of particulate matter to the lake during periods of heavy flow. The bands could represent redeposition or slumping of materials that accumulate in shallow areas, but the results of the 1976 core transect seem to rule out this possibility. Examination of the three cores showed that, as the transect approached the mouth of SWST, sediment bands became much thicker and contained larger-sized particles of inorganic and organic particulate matter (see Plate 5).

The results of the charcoal analysis suggest that bands may have formed as a result of erosion following fires in the watershed. Careful examination of the charcoal profiles shows that the sediment bands are usually associated with high concentrations of charcoal. Charcoal peaks are often one level (.5 cm) above the sediment bands, and it is possible that silt and fine sand that enter the lake at the same time as charcoal settle out more rapidly. Plate 5 shows the core from site 2 where large fragments of charcoal are incorporated in a broad sediment band between 20 and 30 cm. The presence of these fragments, some of which are 2-3 cm long, represents the strongest link between the formation of the bands and the occurrence of fire.

If the Squaw Lake sediment bands are the result of fire-caused erosion, the results of this study help to verify the hypothesis of Swain (1974), who examined the charcoal content of sediments from a small lake in northeastern Minnesota. He observed that laminations in sediments from Lake of the Clouds appear to be thicker where charcoal concentrations are highest. Swain suggests that post-fire erosion may account for the increased thickness of laminations. Swain was not able to study terrestrial-aquatic interactions in as much detail as I have, but his explanation for sediment-band thickening is strongly supported by the results from Squaw Lake.

Two recently published studies lend further support to the fire-erosion hypothesis. Byrne _et al_. (1977) analyzed sediments in the Santa Barbara Channel, California and used charcoal analysis to

Plate 5. Portion of the frozen sediment core from site 2, Squaw Lake.

reconstruct the fire history of the Coast Range of southern California. Byrne _et al_. identified two very dense layers that contian large amounts of charcoal in pre-European sediments. The preliminary results of their study suggest that the dense sediment layers represent fire-flood events. In another study, Cwynar (1978) studied the laminated sediments of Greenleaf Lake on the Precambrian Shield of Ontario. He analyzed charcoal, aluminum, and vanadium influxes and the thickness of varves in the sediments and found that influx values are positively correlated with varve thickness. Aluminum is the second most abundant element in rocks of the Precambrian Shield, and Cwynar, using it as an erosion indicator, concludes that increased varve thickness is the result of fire-caused soil erosion.

Post-fire erosion should not be considered unusual, for it has been reported elsewhere (Anderson 1974, Kittredge 1948, Pierce 1966). Anderson (1976, p. 249) summarizes the effects of fire on water supply and streamflow:

> Burning the forest can increase both water yield and streamflow discharge. The amount of increase will depend on the intensity, severity, and frequency of fire occurrence and on the proportion of the watershed burned. Where much of the foliage is destroyed, interception and evapotranspiration will be reduced. And where the organic layers of the forest floor are consumed and mineral soil exposed, infiltration and soil water storage capacities may be reduced.

The effects of fire on streamflow are of particular importance. Water yield may be significantly increased immediately following fires (Helvey 1974, Wright 1974). As yield increases, flow velocities increase, and for a given channel the probability that erosion will occur also increases. Kittredge (1948) notes that safe velocities of flow for beds of channels of different material vary from .5-1.0 ft/sec for fine sands and loose silt to 13 ft/sec for hard rock. At PST1 flow velocities exceeded 2 ft/sec at discharges of 1.5 ft^3/sec. It is possible that much of the silt that washed into Squaw Lake during intense runoff episodes had previously collected in the stream bed prior to the storm-flow episode. Increased sediment transport following fires would then be an indirect consequence of increased flow.

Because the channels of streams flowing into Squaw Lake are frozen at the time of peak spring runoff, large influxes of particulate matter may historically have been associated with intense precipitation events such as occurred on May 10-11, 1974. If this is true, it may help to explain an inconsistency in the argument that has been presented so far. A striking feature of the sediment stratigraphy of Squaw Lake is the fact that there was no sediment band formed in conjunction with the logging and burning that occurred in the early 20th Century. The forests surrounding the lake were drastically altered by these disturbances, but it is possible that streamflow was not similarly affected. The deciduous species that regenerated following the logging and burning may have resulted in a more rapid stabilization of the hydrologic regime than would have been expected if pine species had regenerated, for the early growth of deciduous species is much more rapid than that of conifers. Cwynar (1978) cites revegetation following light to moderate fires as a reason for his failure to associate erosion-caused varve thickening with all charcoal influx peaks that he identified.

At Squaw Lake, it is possible that precipitation patterns may have affected the response of the watershed to disturbance. Annual precipitation during the period 1905-1920 may have been below normal. Reduced precipitation strongly affects runoff at Squaw Lake (as in 1973), and post-fire precipitation patterns may be a more important factor contributing to sediment band formation than the actual occurrence of fire.

The fact that bands have been formed at Squaw Lake and not other lakes in the area is probably directly related to Squaw Lake's large watershed, its dependence upon surface runoff, and the steepness of the surrounding topography. These factors make Squaw Lake more susceptible to flooding than, for example, Lake Itasca, Elk Lake, or Long Lake.

B. The Replacement of White Pine by Red and Jack Pine

The recent shift from a predominance of Haploxylon to a predominance of Diploxylon pine pollen in the sediments of Squaw Lake probably represents a regional replacement of white pine by red and jack pine. Similar shifts in predominance have been noted by McAndrews (1966) and Janssen (1967), but the studies at Bog D and Stevens Pond leave unanswered questions concerning the time period during which the replacement occurred and the factors leading to the replacement.

Janssen's Stevens Pond diagram is undated, while McAndrew's subzone boundary can be dated only by interpolation from a C-14 date that is 1.25 m below the boundary. The replacement date from the Bog D diagram is 1400 B.P., and McAndrews states that red and jack pine migrated into the Itasca area "about 1,000 years ago." At Squaw Lake, Diploxylon pine pollen first comprises more than 25 percent of the total pine pollen at about 450 B.P. This date is much younger than the Bog D date and may represent a real difference between the two sites. The Squaw Lake date may be more indicative of regional changes, however, since it is taken from a much larger deposition basin (62 ha vs. 1-2 ha).

McAndrews argues that the replacement of white pine by red and jack pine reflects a regional climatic cooling that has proceeded gradually over the past 2000 years. While this may generally be true, the evidence from Squaw Lake suggests that a more detailed explanation may be possible. Specifically, I propose that the sharp drop in white pine pollen percentages at 10 cm occurred as a result of the decimation of white pine by fires that increased in frequency during the 19th Century. Frissell (1971) has determined that intervals between fires in Itasca State Park fell from 12.5 years during the 18th Century to 5.6 years during the latter half of the 19th Century. At Squaw Lake Haploxylon pine pollen drops sharply at 10 cm. This depth dates to about 1825; just after four fires burned the Squaw Lake watershed between 1795 and 1820.

Young white pine trees are more susceptible to fire damage than young red and jack pine (Fowells 1965), and increased fire frequencies should favor the more resistant species. The sharp drop in pine percentages suggests, however, that old-growth white pine were simultaneously being destroyed. The factors causing the destruction of these trees are not clear, but it seems unlikely that intense crown fires were burning in the Squaw Lake area at the turn of the 19th Century. The dense 200-year-old red pine that surrounded the lake in 1900 were 70-100 years old in 1800 and would have been destroyed by such fires. The scars on these trees were probably the result of light ground fires. Such fires rarely damage mature red pine, but results of a recent prescribed burn suggest that they may selectively destroy white pine.

On October 10, 1975 a stand of mature red and white pine in Itasca State Park was burned to test the feasibility of using fire to control brush and reduce buildups of humus. The 4 ha stand is on the LaSalle Trail near the Forestry and Biological Station, is 200-300 years old, and has a dense hazel understory. The stand has been burned in the past, but no fires have been reported in the area since 1895 (Frissell 1971). Because of the lack of recent fire, balsam fir (<u>Abies balsamea</u> [L] Mill.) and white spruce (<u>Picea glauca</u> [Moench] Voss) have invaded the understory, and some of these trees were 5-10 m tall when the stand was burned. The fire burned lightly through the understory, and the crowns of mature pine were little affected by the flames. Although some of the overstory trees were damaged by the fire, red pine and white pine trees were affected by different circumstances. Most of the trees bore fire scars from previous fires. Scars on the white pine had resulted in substantial butt rot, and the boles of many trees were hollowed out. The interior of these boles ignited, and the resulting fires were extremely difficult to suppress. Most burning white pine were saved but some were not. If the butt fires were not extinguished, the fires continued to burn until the entire bole was burned out. Trees affected in this way fell to the ground, usually within 24 hours of the time of the start of the prescribed burn, which itself lasted only 3-4 hours.

Although most of the red pine bore fire scars, few were rotten, and butt fires occurred in only a limited number. Several red pine were killed, however, when their crowns were scorched. All of the killed red pine were in an area where spruce and fir in the understory caught fire. The intense heat generated by these burning conifers carried into the overstory, and the red pine, with their compact rounded crowns, were damaged despite the fact that flames did not actually reach the foliage. White pine trees have narrow crowns with irregularly spaced branches and were little affected by crown damage.

The subjective observations described above were verified six months after the fire by examining all conifer trees on the 4 ha tract. The species, diameter, and crown class were recorded, and notations were made on the presence of fire scars and butt rot. The status of the trees (living or dead) was recorded, and, for the trees killed by the fire an attempt was made to determine if death was caused by butt fire or crown damage. The results of the survey are presented in Table 29.

Table 29. Results of tree sampling at the LaSalle Trail burn.

Genus/Species	Status	Number of Trees	dbh[2]	Crown Class D	Crown Class C	Crown Class I	Crown Class S	Fire Scarred	Butt Rot	Cause of Death Butt Fire	Cause of Death Crown Kill
	Alive	14	9.6±077	1	4	3	6		1		
Abies balsamea									(6.7)		1 (51.6)
	Dead	16(51.6)[1]	4.0±0.60				16		1		
	Alive	50	6.9±0.69	1	7	6	36				
Picea glauca											
	Dead	35(41.2)	3.4±0.47	1		1	33		2(2.3)	1(1.2)	34(40.0)
	Alive	108	17.5±0.37	6	92	4	6	24		3(2.5)	
Pinus resinosa								(25.0)			
	Dead	8(7.4)	18.5±1.63	1	5	2		5	4(3.0)		8(6.9)
	Alive	133	18.4±0.66	11	87	14	22	28	30	9	
Pinus strobus								(23.4)	(24.1)	(9.9)	
	Dead	8(5.7)	14.5±2.82		5	1	2	5	6	5	3(2.1)

[1] Numbers in parenthesis represent the number of trees in a given category expressed as a percent of total number of trees for the species.

[2] dbh in inches ± the standard error of the mean.

Nearly 50 percent of the spruce and fir in the understory were killed by the fire. The average diameter of the dead trees was less than half that of the trees that survived. Of the pines, 7.4 percent of the red pine and 5.7 percent of the white pine were killed. All of the red pine died as a result of crown damage, whereas 5 of 8 white pine were killed by butt fires. An additional three red pine and nine white pine probably would have been killed had not butt fires been extinguished. Twenty-five percent of the red pine had fire scars but only 4 of 29 had butt rot. Only 23 percent of the white pine were fire scarred, but all scarred trees showed evidence of butt rot. (One tree had butt rot but no apparent fire scar.)

The results of the LaSalle Trail burn study suggest that fire frequencies may have governed the dominance of pine species in the Itasca area prior to settlement by European man. When fire intervals are long, white pine is able to regenerate and fire-scarred trees have time to heal between fires. Short fire intervals, however, destroy young white pine and cause repeated scars on older trees that eventually lead to butt rot. By contrast, red pine seedlings require more light than white pine seedlings and cannot regenerate in partial shade. Young red pine, however, have thicker bark and can better withstand light ground fires. The resin that penetrates fire scarred wood on red pine prevents rot, and thus red pine trees are rarely destroyed by butt fires. Longer fire intervals allow the invasion of pine stands by fir and spruce and, when these stands do burn, red pine is more likely to experience crown damage than is white pine.

At Squaw Lake, white pine stands may have regenerated through the 16th Century in response to long fire intervals. As climate cooled, perhaps in conjunction with the Little Ice Age beginning in the late 16th Century, white pine may, however, have lost its competitive advantage. White pine trees probably remained in the overstory and continued to produce pollen, but, by the early 18th Century, extensive red pine stands regenerated on the shores of Squaw Lake. These trees probably began to produce abundant pollen by the middle to late 18th Century. The four major fires that burned at Squaw Lake between 1795 and 1820 may have caused butt fires in many of the remaining white pine and drastically reduced the importance of the species. The sharpness of the decline and the fact that it coincides with a rise in Diploxylon pine pollen suggests that mature red pine were already present in the area. The fact that total pine percentages do not change suggests a simultaneous increase in red and jack pine abundance occurred. Figure 37 depicts data from Frissell (1971) and shows that large acreages of red and jack pine germinated following the fires that burned in the early 19th Century. The maturation of these stands may account for the rising percentages in total pine pollen at the time of settlement.

If recent vegetation changes at Squaw Lake occurred in response to increased fire frequency, the results of this study differ from those of Cwynar (1977, 1978), who reports recent increases in fire frequencies at Greenleaf Lake, Ontario. During the past 300 years

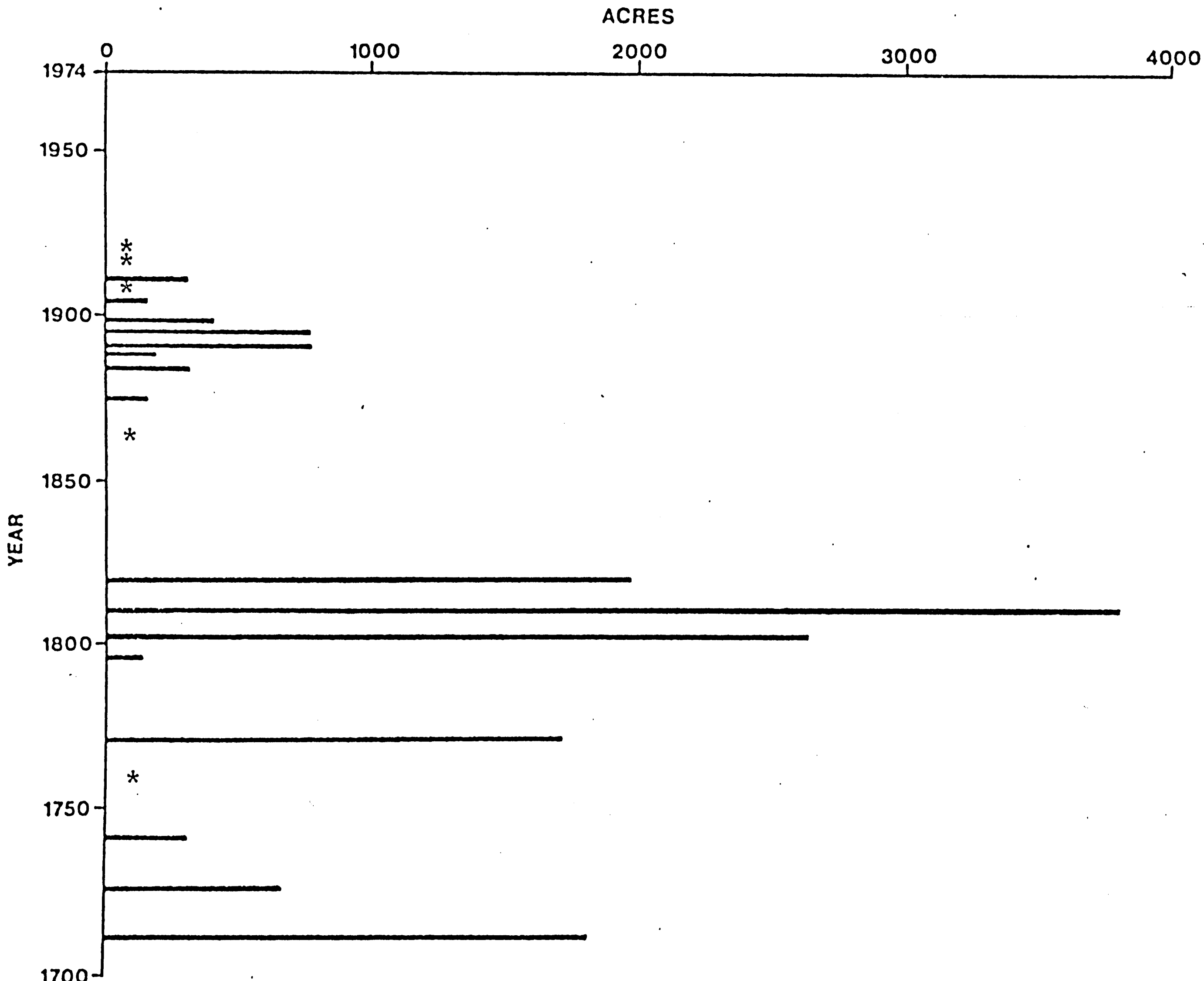


Figure 37. Acreages of red and jack pine regenerating after major fires, 1700-1920. Asterisk indicates no pine regeneration after a fire in the indicated year.

fires have, on the average, occurred once every 45 years at Cwynar's site. Prior to 300 B.P., fires occurred every 80 years, but pollen analysis indicates that increased fire frequency has had no apparent effect on the vegetation communiites of the area. Pinus strobus has remained the dominant taxon (50-60 percent of the total pollen), while Pinus banksiana/resinosa has remained stable at 10-20 percent.

Local site conditions are probably very important in determining the effect of fire frequency on vegetation. White pine is at the extreme western edge of its range at Squaw Lake but in the middle of its range at Greenleaf Lake. Increased sensitivity to changes in climate or disturbance regime may account for the decline of white pine in response to increased fire frequency at Squaw Lake. At Greenleaf Lake, white pine forests apparently withstood three major fires in a 22-year period (1854-1875), whereas the white pine at Squaw Lake were destroyed by the three fires between 1803 and 1821.

The results of the pollen studies at Squaw Lake pose an interesting paradox for the overall pine restoration program. The Squaw Lake pollen diagram shows that the pre-settlement vegetation was not composed of stable communities but had, in fact, recently undergone significant changes.

The forests surrounding Squaw Lake in 1900 were probably the first red pine stands that had occurred there in the past 5000-6000 years. In the absence of man's influence, fire-frequency patterns are probably governed by climatic trends. Climate continues to change, however, and it is possible that even without man's intervention the conditions that gave rise to red pine at Squaw Lake no longer exist. Man cannot control climate, but he can control the occurrence of fire. Even before European man entered the Itasca area, Indians were probably a major cause of fire (Frissell 1971). Today, it might be more reasonable to attempt to reestablish the pre-settlement disturbance regime than to try to reconstruct pre-settlement forests. If disturbance was reintroduced as a major factor governing forest composition, vegetation could then be allowed to develop under circumstances that would more nearly duplicate pre-settlement conditions. Such a program would require careful study of the conditions that lead to major fires and would require an intensive and continuing management program. If this were done, however, controlled burns could be planned and executed in such a way that they would, to some extent, duplicate the natural fire regime. This would seem to be a more valid approach to the pine restoration program than an effort whose sole objective is the reconstruction of forests as they were.

C. The Effect of Vegetative Cover on the Limnology of Squaw Lake.

Despite the difficulties encountered in the throughfall sampling, clear differences between conifer and hardwood ecosystems were observed. It is not clear, however, if the recent conversion of Squaw Lake's watershed to hardwoods has resulted in increased aquatic productivity.

Little information is available on historical changes in Squaw Lake's productivity. The paleolimnological parameters I sampled generally do not reflect productivity. Some data were collected, however, by R.B. Brugam, who sampled fossil diatoms above and below the settlement horizon in the sediments of Squaw Lake. His unpublished data show that Cyclotella comta, which is characteristic of only the clearest lakes in Minnesota, declines in abundance from 21.8 percent at 7 cm to 2.3 percent at the surface. Cyclotella is replaced by Fragilaria crotonensis, a species that increased in abundance when Lake Washington in the state of Washington was impacted by sewage effluents (Stockner and Benson 1967). In Minnesota, however, Brugam has not observed a clear association between F. crotonensis and eutrophication. Comparing his Squaw Lake data with data from other Minnesota lakes, Brugam concludes that at Squaw Lake, the extent of eutrophication in recent years is very small. Thus there has apparently been little recent increase in Squaw Lake's productivity that can be associated with the conversion of the watershed from pine to aspen.

There is evidence to suggest that the recent vegetation change has, however, contributed to higher water levels in Squaw Lake. Cut red pine stumps on the shore of a small bay in the northwest corner of the lake were observed standing in water during the entire study period. Water levels could not have been as high as they now are when the trees that were cut from these stumps were alive, because red pine cannot withstand prolonged flooding (Ahlgren and Hansen 1957).

There is empirical evidence that suggests that the discharge from watersheds is greater under hardwood cover. Swank and Douglass (1974) sampled annual streamflow following the conversion of the vegetation from hardwoods to pine on a small watershed at the Coweeta Hydrologic Laboratory in North Carolina. They found that 20 years after stand conversion annual streamflow from the watershed with pine cover was 20 percent less than could be expected if the vegetative cover consisted of mature deciduous hardwoods. Swank and Douglass cite increased interception and evapotranspiration as factors reducing streamflow from pine-covered watersheds and conclude that similar reductions following stand conversion might be expected in other geographic regions. Combining the results of the Coweeta experiment with the observations at Squaw Lake suggests that the lake's current water levels may represent historic highs.

VII. CONCLUSIONS

"Much is lost forever, our progress through the centuries trailing out behind like something badly woven, its tail always unraveling. What might we know if it didn't?"

Harwood, 1976

The quote by Harwood highlights one of man's fundamental shortcomings. No matter how earnest our intentions or how careful our plans, we invariably fail to record all of the details necessary to interpret and preserve the lessons gained from events that surround us. Paleoecologists serve the scientific community by recovering lost information for, as Solzhenitsyn (1973) points out, "things have longer memories than people." In this study I have been able to use fossils and other historical evidence to reconstruct disturbance effects that would otherwise go unexplained.

Although paleoecological data allow us to overcome temporal limitations, they rarely provide precise reconstructions. I have, therefore, combined paleoecological and neoecological research techniques and gained insights that could not have been attained had either been exclusively employed. The precise data on stream sediment load that were collected at PST1 clearly document, for example, the effects of storms on sediment transport. The sedimentary analyses, on the other hand, strongly suggest that there has been a historic association between fires and erosion. Similarly, the pollen and charcoal analyses document recent, fire-related shifts in vegetation composition at Squaw

Lake. The mechanism responsible for this shift could not have been postulated, however, without observations made at the LaSalle Trail prescribed burn.

Interpretations of the effects of present and past disturbances indicate that current management practices at Squaw Lake are inadequate. A comparison of conifer and deciduous plots of differing ages (Table 30) shows that the two red pine stands (R3 and R4) are distinctive in many ways. Of particular importance are the sparse herb and shrub layers, and, in the sapling pine plot, the poorly-developed forest floor. Successful red pine establishment is directly related to lack of competition and exposure of mineral soil. Neither of these criteria have been met at the aspen and jack pine plots in the Squaw Lake treatment area. This suggests that the terrestrial ecosystem will require more extensive disturbance before pine can replace aspen.

The results of this study also suggest that a greater effort must be directed toward the selection of conversion areas that show a high potential for pine establishment. Management practices have thus far avoided "sensitive" areas. As an example, aspen and birch stands along the shore of Squaw Lake were not logged despite the fact that the densest pre-settlement pine stands occurred there. Similarly, a fire line was built that parallels the shoreline for several hundred meters, when the lake itself could have been safely and effectively used as a fire break. If this had been done, it would have been possible to avoid the construction of a fire break that precluded from burning

Figure 30. Vegetation and soil parameters for selected aspen and pine plots at Squaw Lake.

Cover	Plot	Herbs		Understory			Overstory		Forest Floor	
		No. of Species	Biomass[1]	No. of Species	Basal Area[2]	Stem Density[3]	Basal Area[4]	Stem Density[5]	Depth[6]	Weight[1]
Mature aspen	V3	20	69.9	11	6.9	21.3	23.4	1150	3.0	2841
Clearcut aspen	V4	18	93.7	10	4.6	37.8	0	0	2.9	2369
Clearcut/burn aspen	V5	30	232.3	9	5.2	47.1	0	0	----	----
Sapling aspen	Z	32	67.5	12	4.7	15.5	9.0	9750	3.1	2902
Mature jack pine	J3	22	39.5	11	5.1	14.5	31.5	725	4.0	3365
Clearcut jack pine	J4	23	66.8	8	2.5	29.9	0.1	25	4.1	3950
Clearcut/burn jack pine	J5	34	226.3	12	1.8	75.9	0	0	----	----
Pole red pine	R3	17	25.9	9	0.4	5.0	49.7	1750	5.5	4509
Sapling red pine	R4	39	47.6	16	1.7	22.7	2.3	1750	1.4	899

1 g/m^2

2 cm^2/m^2

3 $\#/m^2$

4 m^2/ha

5 #/ha

6 cm

some of the areas most suited for conversion. Also, the 55 year old pine stand at plot R3 could have been burned. Periodic burning of maturing pine stands will eventually be necessary in order to reduce accumulations of litter, recycle nutrients, and prevent the invasion of shrubs.

In addition to suggesting revised management practices, this thesis has broader implications for the study of the role of disturbance in natural ecosystems. Too frequently, past research efforts have concentrated on post-disturbance stabilization processes. This approach invariably leads to the conclusion that disturbance is an alien and destructive force in balanced ecosystems. Disturbances are, however, a natural part of ecosystem dynamics, and emphasis should be placed on the study of ecosystem responses to repeated disturbances. If this were done, periods of relative stability could be viewed as discrete intervals leading to successive disturbances rather than indefinite epochs to be preserved as long as possible. Certainly species have evolved in response to continuing stresses, and eventually it may be demonstrated that ecosystem processes have evolved in a similar manner.

IX. LITERATURE CITED

Aaseng, N.E. 1976. The history, nature, and extent of the major logging operations in Itasca State Park (1901-1919). M.S. thesis, Univ. Minn. 41 p.

Ahlgren, C.E., and H.L. Hansen. 1957. Some effects of temporary flooding on coniferous trees. J. For. 55:647-650.

Alban, D.H. 1974. Soil variation and sampling under red pine and aspen in Minnesota. USDA For. Serv. Res. Pap. NC-106. 10 p.

Alban, D.H. 1976. Estimating red pine site index in northern Minnesota. USDA For. Serv. Res. Pap. NC-130. 13 p.

Alban, D.H. 1977. Influences on soil properties of prescribed burning under mature red pine. USDA For. Serv. Res. Pap. NC-139. 8 p.

American Public Health Assoc. 1971. Standard methods for examination of water and waste water. Amer. Public Health Assoc., New York. 874 p.

Amundsen, D.C. 1974. The early postglacial transition from spruce forest to pine forest in Minnesota. M.S. thesis, Univ. Minn. 70 p.

Anderson, H.W. 1974. Sediment deposition in reservoirs associated with rural roads, forest fires and catchment attributes. Proc. Symp. Man's Effect on Erosion and Sedimentation, Paris, Sept. 9-12, 1974:87-95.

Anderson, H.W. 1976. Fire effects on water supply, floods and sedimentation. Proceedings, Annual Tall Timbers Fire Ecology Conference No. 15:249-259.

Anthony, R.S. 1976. Iron-rich rhythmically laminated sediments in Lake of the Clouds, northeastern Minnesota. Limnol. Oceanogr. 22:45-54.

Benninghoff, W.S. 1962. Calculation of pollen and spores density by addition of exotic pollen in known quantities. Pollen in known quantities. Pollen et Spores 6:332-333.

Birks, H.B., M.C. Whiteside, D.M. Stark, and R.C. Bright. 1976. Recent paleolimnology of three lakes in northwestern Minnesota. Quat. Res. 6:249-272.

Blair, R.M., and L.E. Brunett. 1976. Phytosociological changes after timber harvest in a southern pine ecosystem. Ecology 57:18-32.

Blake, G.R. 1965. Bulk density. p. 374-390 In C.A. Black [ed.] Methods of soil analysis. Agronomy 9:374-390.

Bonnewell, V. 1974. Investigation of the composition of sediment and the process of sedimentation in several Minnesota lakes. Unpubl. Rpt. for BOT 8990, Univ. Minn. 17 p.

Bowersox, T.W., and W.W. Ward. Temporal variation in nutrient levels of litter in black cherry stands. For. Sci. 23:429-432.

Bradbury, J.P., and J.C.B. Waddington. 1973. The impact of European settlement on Shagawa Lake, northeastern Minnesota, U.S.A. p. 289-308 In H.J.B. Birks and R.G. West [ed.] Quaternary plant ecology. Blackwell Scientific Publ., Oxford.

Bray, R.H., and L.T. Kurtz. 1945. Determination of total organic, and available forms of phosphorus in soils. Soil Sci. 59:39-45.

Brower, J.V. 1893. The Mississippi River and its sources. An historical and illustrated geographical record. Minn. Hist. Soc. Coll. Vol. VII. Harrison and Smith, Minneapolis. 360 p.

Brower, J.V. 1904. Itasca State Park, an illustrated history. Minn. Hist. Soc. Coll. Vol. XI. Minn. Hist. Soc., St. Paul, Minn. 285 p.

Brown, J.K. 1966. Forest floor fuels in red and jack pine stands. USDA For. Ser. Res. Note NC-9. 3 p.

Brugam, R.B. 1975. The human disturbance history of Linseley Pond, North Branford, Connecticut. Ph.D. thesis, Yale Univ. 185 p.

Buckman, R.E. 1961. Development and use of three stand volume equations for Minnesota. J. For. 59:573-575.

Buckman, R.E. 1965. Silvicultural use of prescribed burning in the Lake States. Proc. Soc. Am. For. 1964:38-39.

Byrne, R., J. Michaelsen, and A. Soutar. 1977. Fossil charcoal as a measure of fire frequency in Southern California: a preliminary analysis. p. 361-369 In Proc. Symp. on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. USDA For. Serv. Gen. Tech. Rep. WO-3.

Clements, F.E. 1928. Plant succession and indicators. Wilson Co., New York. 453 p.

Chapman, H.D., and P.F. Pratt. 1961. Methods of analysis for soils, plants and waters. Univ. of Calif. Div. Agr. Sci. 309 p.

Cushing, E.J., and H.E. Wright, Jr. 1965. Hand operated piston corers for lake sediments. Ecology 46:380-384.

Cwynar, L.C. 1977. The recent fire history of Barron Township, Algonquin Park. Can. J. Bot. 55:1524-1538.

Cwynar, L.C. 1978. Recent history of fire and vegetation from laminated sediment of Greenleaf Lake, Algonquin Park, Ontario. Can. J. Bot. 56:10-21.

Davis, M.B. 1972. Redeposition of pollen grains in lake sediments. Limnol. Oceanogr. 18:44-52.

Davis, R.B. 1967. Pollen studies of near-surface sediments in Maine lakes. p. 143-173 In E.J. Cushing and H.E. Wright, Jr. [ed.] Quaternary Paleoecology. Yale Univ. Press, New Haven.

Davis, R.B. 1974. Stratigraphic effects of tubificids in profundal sediments. Limnol. Oceanogr. 19:466-488.

Dean, W. 1974. Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition:comparison with other methods. J. Sed. Petr. 44:242-248.

Dixon, W.J. [ed.] 1976. BMD Biomedical computer programs. Univ. Calif. Press. Berkeley, Calif. 773 p.

Dobie, J. 1959. The Itasca story. Ross and Haines, Inc., Minneapolis. 202 p.

Doty, R.D. 1970. A portable, automatic water sampler. Water Resour. Res. 6:1787-1788.

Douglass, J.E., and W.T. Swank. 1972. Streamflow modification through management of eastern forests. USDA For. Serv. Res. Pa. SE-94 15 p.

Eaton, J.S., G.E. Likens, and F.H. Bormann. 1973. Throughfall and stem flow chemistry in a northern hardwood forest. J. Ecol. 61:495-508.

Edmondson, W.T. 1977. Formation of recent laminations in sediments of Lake Washington. SIL Abstracts 20:69.

Environmental Protection Agency. 1971. Methods for chemical analysis of water and wastes. USEPA 16020. Water Quality Office, Analytical Quality Control Laboratory, Cincinnati, Ohio. 312 p.

Faegri, K., and J. Iversen, 1964. Textbook of pollen analysis. Hafner Publ. Co., New York. 237 p.

Foster, D.C. 1976. Lower LaSalle Lake, Minnesota: sedimentation and recent fire and vegetation history. M.S. thesis, Univ. Minn. 103 p.

Fowells, H.A.[ed.] 1965. Sivics of forest trees of the United States. USDA Agic. Handb. 271. 762 p.

Fredskild, B. 1967. Paleobotanicle investigations at Sermermiut, Jakobshavn, West Greenland. Meddr. Grønland 178(4). 54 p.

Frissell, S.S. 1971. Analysis of the maintenance of presettlement biotic communities as an objective of management in Itasca State Park, Minnesota. Ph.D. thesis, Univ. Minn. 228 p.

Galle, D.K., and R.T. Runnels. 1960. Determination of CO_2 in carbonate rocks by controlled loss on ignition. J. Sed. Petr. 30:613-618.

Gerhart, D.Z. 1973. Nutrient limination and production of phytoplankton in Mirror Lake, West Thornton, N.H. Ph.D. thesis, Cornell Univ. 160 p.

Golterman, H.L. 1969. Methods for chemical analysis of fresh waters. Blackwell Sci. Publ., Oxford. 166 p.

Goulden, G.E. 1966. LaAguada de Santa Ana Vieja: an interpretive study of the cladoceran microfossils. Arch. Hydrobiol. 62:373-404.

Greig-Smith, P. 1964. Quantitive plant ecology. Academic Press, New York. 198 p.

Grigal, D.F. 1973. Note on the hydrometer method of particle-size analysis. Minn. For. Res. Notes No. 245. 4 p.

Hansen, H.L., and D.P. Duncan. 1954. The management of the Itasca State Park forest to meet recreational objectives. Proc. Soc. Amer. For. 1954: 123-125.

Hansen, H.L., V. Kurmis, and D.D. Ness. 1974. The ecology of upland forest communities and implications for management in Itasca State Park, Minnesota. Univ. Minn. Agric. Exp. Sta. Tech. Bull. 298. 43 p.

Harr, R.D. 1976. Forest practices and streamflow in western Oregon. USDA For. Serv. Gen. Tech. Rep. PNW-49. 18 p.

Harwood, M. 1976. The view from Great Gull. E.P. Dutton & Co., Inc., New York. 139 p.

Heinselman, M.L. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quat. Res. 3:329-382.

Helvey, J.D. 1971. A summary of rainfall interception by certain conifers of North America. p. 103-113 In E.J. Monke [ed.] Biological effects in the hydrological cycle. Proc. Third International Seminar for Hydrology Professors. Agric. Exp. Sta., West Lafayette, Ind.

Helvey, J.D. 1974. First-year effects of wildfire on water yield and stream temperature in northcentral Washington. p. 308-312 In S.C. Csalany, T.G. McLaughlin and W.D. Striffler [ed.] Proc. Symp. Watersheds in Transition. Am. Water Resour. Assoc., Urbana, Ill.

Helvey, J.D., and J.H. Patric. 1965. Canopy and litter interception of rainfall by hardwoods of eastern United States. Water Resour. Res. 1:193-206.

Henry, J.D., and J.M.A. Swan. 1974. Reconstructing forest history from live and dead plant material--an approach to the study of forest succession in southwest New Hampshire. Ecology 55:772-783.

Hutchinson, G.E. 1975. A treatise on limnology, Vol. 1., Part 1. John Wiley and Sons, New York. 540 p.

Iversen, J. 1934. Moorgeologische Untersuchungenauf Grönland. Meddr. Dansk. Geol. Foren. 8:341-358.

Iversen, J. 1941. Land occupation in Denmark's Stone Age. Danmark's Geol. Unders. II(66). 68 p.

Iversen, J. 1964. Retrogressive vegetational succession in the postglacial. J. Ecol. 52(Suppl.):59-70.

Janssen, C.R. 1967. Stevens Pond. A postglacial pollen diagram from a small typha swamp in northwestern Minnesota, interpreted from pollen indicators and surface samples. Ecol. Monogr. 37:145-172.

Kirkby, M.J., and R.J. Chorley, 1967. Throughfall, overland flow and erosion. Bull. Int. Assoc. Sci. Hydrol. 12:5-21.

Kittredge, J. 1948. Forest influences. McGraw-Hill Book Co., New York. 394 p.

Klemmer, A.R. 1973. Factors affecting the vertical distribution of a blue-green alga. Ph.D. thesis, Univ. Minn. 69 p.

Klukas, R.W., and D.P. Duncan. 1967. Vegetational preferences among Itasca Park visitors. J. For. 65:18-21.

Kurmis, V. 1969. Dynamics of advance reproduction in upland forest communities in Itasca State Park, Minnesota. Ph.D. thesis, Univ. Minn. 166 p.

Lavrenko, E.M. 1959. Field geobotany, Vol. 1. Publ. Acad. Sci. U.S.S.R., Moscow.

Leisman, G.A. 1957. A vegetation and soil chronosequence on the Mesabi Iron Range spoil banks, Minnesota. Ecol. Monogr. 27:221-245.

Likens, G.E., F.H. Bormann, N.M. Johnson, and R.S. Pierce. 1967. The calcium, magnesium, potassium and sodium budgets for a small forested ecosystem. Ecology 48:772-785.

Likens, G.E., F.H. Bormann, N.M. Johnson, D. Fisher, and R.S. Pierce. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook Watershed ecosystem. Ecol. Monogr. 40:23-47.

Likens, G.E. [ed.] 1972. Nutrients and eutrophication: The limiting-nutrient controversy. Spec. Symp., Am. Soc. Limnol. Oceanogr. Lawrence, Ka. 328 p.

Mace, A.C., Jr., T. Williams, and J.C. Tappeiner, II. 1971. Effect of winter harvesting methods on soil bulk density and infiltration rates. Minn. For. Res. Notes No. 228. 4 p.

Margalef, R. 1968. Perspectives in ecological theory. Univ. Chicago Press, Chicago. 111 p.

McAndrews, J.H. 1966. Postglacial history of prairie, savana, and forest in northwestern Minnesota. Torrey Bot. Club Mem. 22(2), 72 p.

McAndrews, J.H., A.A. Berti, and G. Norris. 1973. Key to the Quaternary pollen and spores of the Great Lakes region. Royal Ontario Museum, Toronto. 61 p.

McColl, J.G., and D.F. Grigal. 1975. Forest fire: Effects on phosphorus movement to lakes. Science 188: 1109-1111.

Megahan, W.F. 1974. Subsurface flow interception by a logging road in mountains of central Idaho. p. 350-356 In S.C. Csalany, T.G. McLaughlin and W.D. Striffler [ed.] Proc. Symp. Watersheds in Transition. Amer. Water Resour. Assoc., Urbana, Ill.

Megard, R.O. 1968. Planktonic photosynthesis and the environment of calcium carbonate deposition in lakes. Interim Report No. 2, Limnol. Res. Cntr., Univ. Minn. 47 p.

Meyer, M.P. 1966. The vegetation of Itasca State Park (a map). School For., Univ. Minn. St. Paul, Minn.

Muller, R.N., and F.H. Bormann. 1976. Role of Erythronium americanum Ker. in energy flow and nutrient dynamics of a northern hardwood forest ecosystem. Science 193:1126-1128.

Ness, D.D. 1971. Comparative dynamics of upland forest communities in Itasca State Park, Minnesota. Ph.D. thesis, Univ. Minn. 447 p.

Noble, M.G., L.K. DeBoer, K.L. Johnson, B.C. Coffin, L.G. Fellows and N.A. Christensen. 1977. Quantitative relationships among some Pinus banksiana-Picea mariana forests subjected to wildfire and post-logging treatments. Can. J. For. Res. 7:368-377.

Oliver, C.D., and E.P. Stevens. 1977. Reconstruction of a mixed-species forest in central New England. Ecology 58:562-572.

Orloci, L. 1967. An agglomerative method for classification of plant communities. Ecology 55:193-206.

Ownbey, G.B. 1969. Annotated checklist of the seed plants, ferns and fern allies (Division Tracheophyta) for Clearwater County and Itasca State Park Minnesota. Univ. Minn. 66 p.

Patterson, W.A. 1976. Charcoal as a fossil indicator of fire. Unpubl. Rpt. for FBIO 8104, Univ. Minn. 65 p.

Perala, D.A. 1974. Growth and survival of northern hardwood sprouts after burning. USDA For. Serv. Res. Note NC-176. 4 p.

Perala, D.A. 1977. Manager's handbook for aspen in the north-central states. USDA For. Serv. Gen. Tech. Rep. NC-36. 30 p.

Pierce, R.S. 1966. Evidence of overland flow in forest watersheds. Int. Symp, Forest Hydrol., 247-252. Pergammon Press, New York.

Reiners, W.A., and N.M. Reiners. 1970. Energy and nutrient dynamics of forest floors in three Minnesota forests. J. Ecol. 58:497-520.

Roepke, H.H. 1959. p 50-105 In G.M. Schwart et al. Investigation of the commercial possibilities of marl in Minnesota. Iron Range Res. and Rehab. Comm., St. Paul, Minn.

Ruttner, F. 1972. Fundamentals of Limnology. Univ. Toronto Press. 295 p.

Salisbury, E.J., and F.W. Jane. 1940. Charcoals from Maiden Castle and their significance in relation to the vegetation and climatic conditions in prehistoric times. J. Ecol. 28:310-325.

Schiff, A.L. 1960. Fire and Water. McGraw-Hill Publ. Co., New York. 225 p.

Shapiro, J. 1958. The core-freezer--a new sampler for lake sediments. Ecology 39:758.

Shapiro, J. 1973. Blue-green algae:Why they become dominant. Science 179:382-384.

Shay, C.T. 1971. The Itasca bison kill site; An ecological anslysis. Minn. Hist. Soc., St. Paul. 133 p.

Shindler, D.W. 1974. Eutrophication and recovery in experimental lakes: Implications for lake management. Science 184: 897-899.

Solzhenitsyn, A. 1973. The Gulag Archipelago 1918-1956: An experiment in literary investigation I-II. Harper & Row, Publ. 660 p.

Spurr, S.H. 1954. The forests of Itasca in the nineteenth century as related to fire. Ecology 35:21-25.

Stark, D.M. 1976. Paleolimnology of Elk Lake, Itasca State Park, northwestern Minnesota. Arch. Hydrobiol./Suppl. 50: 208-274.

Stevens, E.P. 1956. The uprooting of trees: A forest process. Soil Sci. Soc. Am. Proc. 20:113-116.

Stockner, J.G., and W.W. Benson. 1967. The succession of diatom assemblages in the recent sediments of Lake Washington. Limnol. Oceanogr. 12:513-532.

Sukachev, V., and N. Dylis. 1968. Fundamentals of forest biogeocoenology. Oliver and Boyd, Ltd., Edinburgh. 642 p.

Swain, A.M. 1974. A history of fire and vegetation in northeastern Minnesota as recorded in lake sediments. Ph.D. thesis, Univ. Minn. 89 p.

Swain, F.M. 1966. Geochemistry of some Quaternary lake sediments of North America. p. 765-782 In H.E. Wright, Jr. and D.G. Frey [ed.] The Quaternary of the United States. Princeton Univ. Press., Princeton.

Swain, F.M., and N. Prokopovich. 1954. Stratigraphic distribution of lipoid substances in Cedar Creek Bog, Minnesota. Geol. Soc. Amer. Bull. 65:1183-1189.

Swank, W.T., and J.E. Douglass. 1974. Streamflow greatly reduced by converting deciduous hardwood stands to pine. Science 185: 857-859.

Tandon, H., M.P. Cescas, and E.H. Tyner. 1968. An acid-free vanadate-molybdate reagent for the determination of total P in soils. Soil Sci. Soc. Amer. Proc. 32:48-51.

Tansley, A.G. 1929. Succession: The concept and its values. Proc. Intern. Congress Plant Sci. 1926:677-686.

Tansley, A.G. 1935. The use and abuse of vegetational concepts and terms. Ecology 16:284-307.

Tappeiner, J.C., II, and A.A. Alm. 1975. Undergrowth vegetation effects on the nutrient content of litterfall and soils in red pine and birch stands in northern Minnesota. Ecology 56:1193-1200.

U.S. Department of Agriculture. 1972. Soil survey laboratory methods and procedures for collecting soil samples. SCS Soil Surv. Invest. Rep. No. 1. 63 p.

Vandersluis, C. 1974. Mainly logging. Minneota Clinic. Minnesota. 372 p.

Verry, E.S. 1974. Effects of an aspen clearcutting on water yield and quality in northern Minnesota. p. 276-284 In S.C. Csalany, T.G. McLaughlin, and W.D. Striffler [ed.] Proc. Symp. Watersheds in Transition. Amer. Water Resour. Assoc., Urbana, Ill.

Waddington, J.C.B. 1969. A stratigraphic record of the pollen influx to a lake in the Big Woods of Minnesota. Geol. Soc. Am. Spec. Pap. 123:263-282.

Warner, M.H., and J.B. Jones, Jr. 1970. A rapid method for nitrogen determination in plant tissue. Soil Sci. and Plant Anal. 1:109-114.

Weaver, J.E., and F.E. Clements. 1938. Plant ecology. McGraw-Hill Book Co., New York. 601 p.

Wells, C.A., D. Whigham, and H. Lieth. 1972. Investigation of mineral nutrient cycling in an upland Piedmont forest. J. Elisha Mitchell Sci. Soc. 88:66-78.

Whittaker, R.H. 1951. A criticism of the plant association and climatic climax concepts. Northwest Sci. 25:17-31.

Whittaker, R.H. 1956. Vegetation of the Great Smokey Mountains. Ecol. Monogr. 26:1-80.

Whittaker, R.H. 1957. Recent evolution of ecological concepts in relation to the eastern forests of North America. Amer. J. Bot. 44:197-206.

Whittaker, R.H. 1960. Vegetation of the Siskiyou Mountains, Oregon and California. Ecol. Monogr. 30:279-338.

Wilde, S.A., G.K. Voigt, and I.G. Iyer. 1972. Soil and plant analysis for tree culture. Oxford and IBM Publ. Co., New Delhi, 172 p.

Williams, T.M. 1974. The influence of alternative harvesting systems on leaching of natural and artificially applied major nutrient elements. Ph.D. thesis, Univ. Minn. 161 p.

Woodhead, T.W. 1924. The age and composition of the Pennine peat. J. Bot. 62:301-304.

Wright, H.E., Jr., and R.V. Ruhe. 1965. Glaciation of Minnesota and Iowa. p. 29-41 In H.E. Wright, Jr. and D.G. Frey [ed.] The Quaternary of the United States. Princeton Univ. Press, Princeton. 922 p.

Wright, R.F. 1974. Forest fire: Impact on the hydrology, chemistry, and sediments of small lakes in northeastern Minnesota. Interim Report No. 10. Univ. Minn., Limnol. Res. Cntr., Minneapolis. 128 p.

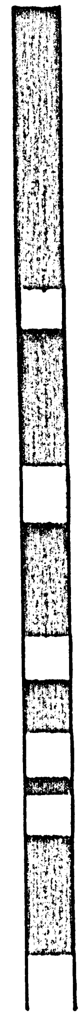
Zavitkovski, J. 1976. Ground vegetation biomass, production, and efficiency of energy utilization in some northern Wisconsin forest ecosystems. Ecology 57:694-706.

IX. APPENDICES

Appendix A. Squaw Lake sediment characteristics.

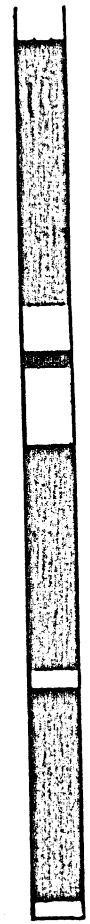
SAMPLE DEPTH (MM.)	PARTICULATE MATTER TOTAL	INORGANIC	ORGANIC	WATER	ASH	AUTO-TECH. PHOSPHORUS	E.S. CALCIUM	E.S. ALUMINUM	A.A. IRON	E.S. MAGNESIUM	E.S. ZINC	E.S. MANGANESE	E.S. BORON
	------- GM./CC. -------			------------		----------- %	------------				--------	PPM	-------
3	.0227	.0141	.0086	97.6	62.0	1.35	1.0	.65	14.55	.3	860.	6200.	100.
8	.0550	.0352	.0198	94.0	64.1	1.11	.9	.68	11.04	.3	140.	5400.	70.
13	.0630	.0416	.0214	93.1	66.0	.95	.8	.70	10.20	.3	120.	4500.	70.
18	.0878	.0454	.0224	92.6	66.9	.98	.8	.68	9.62	.3	110.	4600.	80.
23	.0733	.0488	.0245	92.4	66.6	1.05	.9	.66	10.50	.3	130.	5000.	70.
28	.0879	.0615	.0265	90.8	69.9	1.13	.8	.58	9.36	.2	110.	4600.	70.
33	.0872	.0594	.0277	90.8	68.2	1.13	.7	.58	9.74	.2	100.	5600.	80.
38	.0865	.0566	.0299	91.3	65.4	1.13	.6	.56	10.17	.2	100.	5200.	80.
43	.0810	.0508	.0301	91.9	62.8	1.11	.7	.56	9.59	.2	110.	5200.	70.
48	.0797	.0488	.0309	92.2	61.2	1.13	.8	.50	13.17	.2	120.	8000.	90.
53	.0808	.0506	.0303	91.9	62.5	1.26	.6	.43	19.58	0	90.	8000.	110.
58	.0810	.0511	.0299	91.7	63.1	1.29	.7	.61	19.80	.2	100.	7400.	90.
63	.0798	.0498	.0300	91.8	62.5	1.20	.8	.63	15.45	.2	140.	7100.	100.
68	.1017	.0706	.0310	89.7	69.5	1.28	.9	.70	14.55	.3	120.	5500.	70.
73	.0881	.0584	.0297	90.8	66.3	1.43	.8	.62	16.35	.3	100.	7000.	80.
78	.1427	.1099	.0327	86.2	77.0	1.04	1.3	1.08	11.43	.7	80.	6700.	80.
83	.1393	.1077	.0316	86.5	77.3	1.10	1.0	.78	11.43	.5	70.	6500.	80.
88	.1131	.0797	.0334	88.8	70.5	1.35	.8	.87	15.15	.4	90.	6600.	80.
93	.0999	.0659	.0340	90.0	66.0	1.20	.7	.72	14.55	.3	100.	5800.	80.
98	.1045	.0701	.0344	89.7	67.0	1.49	.8	.72	17.12	.3	90.	6100.	80.
103	.0987	.0649	.0338	90.1	65.8	1.26	.7	.64	18.00	.2	100.	6500.	80.
108	.0969	.0649	.0320	90.0	66.9	1.50	.7	.63	19.29	.2	110.	7400.	90.
113	.0996	.0661	.0336	90.0	66.3	1.38	.9	.73	18.35	.2	110.	7500.	80.
118	.1195	.0829	.0366	88.2	69.4	1.35	1.1	.90	14.85	.4	110.	5900.	60.
123	.1545	.1218	.0327	84.8	70.8	.98	1.4	.78	12.75	.6	70.	6100.	80.
128	.1923	.1560	.0382	81.7	81.1	1.20	1.6	1.16	9.87	.7	70.	5800.	70.
133	.2960	.2604	.0356	73.7	88.0	.50	1.9	.76	5.40	1.0	30.	2800.	30.
138	.1362	.0995	.0367	86.6	73.0	1.28	1.0	.95	15.15	.4	100.	6800.	80.
143	.1076	.0751	.0325	89.4	69.8	1.25	.9	.64	23.45	.2	90.	9200.	100.
148	.1131	.0794	.0338	88.7	70.1	1.35	.9	.67	18.33	.2	90.	9300.	90.
153	.1222	.0850	.0371	88.1	69.6	1.43	.9	.90	15.45	.3	120.	8400.	90.
158	.1169	.0807	.0361	88.4	69.1	1.55	1.0	.82	20.05	.3	90.	8800.	100.
163	.1504	.1084	.0419	85.4	72.1	1.25	.9	1.03	11.15	.5	90.	7400.	90.
168	.2417	.2004	.0414	78.1	82.9	.75	1.5	1.27	6.72	.9	70.	4300.	60.
173	.2762	.2362	.0400	75.4	85.5	.60	1.8	1.20	5.85	1.0	50.	5100.	60.
178	.1075	.1412	.0463	82.3	75.3	1.31	1.3	1.07	9.56	.6	90.	7700.	70.
183	.1658	.1163	.0495	84.0	70.1	1.44	.9	1.10	11.76	.4	90.	7200.	70.
188	.1867	.1388	.0479	82.2	74.4	1.41	.9	1.04	9.27	.5	110.	6300.	60.
193	.2224	.1770	.0454	79.4	79.6	.98	1.5	1.25	7.29	.8	90.	4500.	40.
198	.2306	.1852	.0455	79.0	80.3	.74	1.5	1.19	6.30	.8	70.	4700.	50.
203	.1984	.1517	.0466	81.5	76.5	.85	1.4	1.34	6.30	.7	70.	4700.	40.
208	.2431	.1936	.0495	77.3	79.6	.42	1.5	1.16	5.23	.7	70.	3400.	50.
213	.2348	.1847	.0500	78.4	78.7	.46	1.4	1.20	5.10	.7	60.	3300.	40.
218	.2034	.1515	.0520	80.9	74.5	.57	1.0	1.28	4.65	.6	60.	3000.	40.
223	.1997	.1464	.0533	81.4	73.3	.32	.8	1.30	4.65	.4	60.	2700.	0
228	.2065	.1512	.0553	80.9	73.2	.47	.9	1.40	3.30	.5	60.	2400.	0
233	.2039	.1486	.0554	80.9	72.8	.36	.8	1.39	3.75	.4	60.	2500.	30.
238	.2008	.1464	.0543	81.2	72.9	.39	.9	1.31	4.65	.5	50.	2300.	40.
243	.2053	.1509	.0544	81.1	73.5	.52	.9	1.36	4.20	.5	50.	2400.	0
248	.2377	.1870	.0507	78.4	78.7	.24	.9	1.23	6.30	.6	50.	1800.	30.
253	.3274	.2786	.0488	71.6	85.1	.14	1.4	1.26	2.55	.9	40.	1300.	0
258	.4382	.3887	.0495	84.3	88.7	.16	1.6	1.16	1.65	1.0	30.	1100.	0

LITHOLOGY



SAMPLE DEPTH (MM.)	PARTICULATE MATTER TOTAL (GM./CC.)	INORGANIC (GM./CC.)	ORGANIC (GM./CC.)	WATER (%)	ASH (%)	AUTO-TECH. PHOSPHORUS (%)	E.S. CALCIUM (%)	E.S. ALUMINUM (%)	A.A. IRON (%)	E.S. MAGNESIUM (%)	F.S. ZINC (PPM)	F.S. MANGANESE (PPM)	F.S. BORON (PPM)
263	.3882	.3406	.0477	87.7	66.1	.18	1.6	1.19	1.95	.9	40.	1700.	0
268	.2601	.2109	.0491	81.1	76.8	.58	1.3	1.13	5.25	.7	40.	3900.	40.
273	.1796	.1303	.0495	72.5	83.2	1.07	.9	.96	9.90	.4	70.	7700.	80.
278	.1541	.1052	.0489	68.3	85.3	.93	.8	1.05	11.85	.3	110.	8100.	80.
283	.1564	.1064	.0500	68.0	85.2	1.18	.8	.91	11.55	.3	80.	7500.	80.
288	.1486	.0980	.0508	65.9	85.6	1.98	.7	.90	12.30	.3	90.	6300.	60.
293	.1454	.0941	.0513	64.7	85.8	1.12	.7	.81	13.20	.2	100.	6500.	80.
298	.1287	.0831	.0456	64.6	87.4	1.39	.7	.75	17.25	.2	120.	7200.	100.
303	.1232	.0788	.0444	63.9	88.0	.81	.7	.85	15.75	.2	110.	8000.	90.
308	.1512	.0969	.0543	64.1	85.2	1.04	.8	1.03	15.30	.2	140.	8300.	80.
313	.1435	.0915	.0520	63.8	85.9	1.14	.6	1.02	11.10	.2	140.	7900.	70.
318	.1704	.1143	.0560	67.1	83.6	1.50	.5	1.05	8.25	.3	130.	5600.	60.
323	.1893	.1250	.0643	66.0	82.0	1.10	.6	1.13	6.15	.3	110.	4400.	50.
328	.2386	.1675	.0710	70.2	77.9	1.04	.6	1.15	7.65	.3	110.	3900.	50.
333	.1826	.1333	.0494	73.0	82.6	1.02	.7	1.20	7.35	.4	110.	4600.	50.
338	.3439	.2740	.0699	79.7	69.8	.59	.8	.97	4.95	.5	50.	2800.	30.
343	.3334	.2835	.0498	85.0	71.2	.54	1.5	1.04	3.75	.9	40.	2300.	0
348	.2938	.2438	.0499	83.0	73.9	.60	1.4	1.06	4.80	.8	50.	3200.	0
353	.1962	.1458	.0504	74.3	81.7	.93	.8	1.05	8.55	.4	70.	5600.	40.
358	.2446	.1972	.0473	80.6	77.8	.50	1.0	.98	6.75	.6	50.	3600.	50.
363	.2213	.1695	.0518	76.6	79.6	.85	.9	.98	6.60	.5	60.	4600.	50.
368	.2133	.1586	.0547	74.4	80.2	1.48	.9	1.02	6.45	.5	80.	4700.	40.
373	.2113	.1541	.0572	72.9	80.4	.99	.9	1.00	6.75	.5	80.	4000.	40.
378	.1594	.1048	.0546	65.8	84.7	1.09	.6	.87	10.05	.3	100.	5700.	60.
383	.1418	.0883	.0535	62.3	86.4	1.01	.9	.96	11.42	.2	150.	8000.	80.
388	.1399	.0870	.0529	62.2	86.5	1.07	.6	.77	13.35	.2	110.	8400.	70.
393	.1464	.0900	.0564	61.5	85.8	1.77	1.0	1.15	16.50	.3	190.	9800.	80.
398	.1514	.0884	.0630	58.4	85.5	.87	.6	.88	6.15	.2	140.	4600.	30.
403	.1473	.0871	.0602	59.1	85.6	1.04	.6	.91	8.25	.2	120.	4600.	30.
408	.1506	.0905	.0601	60.1	85.4	1.46	.6	.85	11.40	.2	140.	7100.	50.
413	.1686	.1028	.0658	61.0	83.8	1.50	.5	.85	7.65	.2	140.	6800.	40.
418	.1639	.1026	.0613	62.6	84.1	1.31	.6	.89	8.25	.2	120.	5900.	50.
423	.2319	.1525	.0794	65.8	77.9	1.85	.7	.83	6.36	.3	90.	5300.	50.
428	.2345	.1609	.0736	68.6	77.3	1.92	.7	.81	7.55	.3	90.	5300.	40.
433	.1073	.1325	.0548	70.7	81.9	1.77	.7	.64	9.12	.3	80.	5000.	60.
438	.2144	.1598	.0546	74.5	79.6	1.01	.9	.68	8.36	.4	80.	5600.	50.
443	.2309	.1681	.0628	72.8	78.2	2.37	.8	.72	8.37	.3	90.	5800.	50.
448	.2528	.1621	.0907	64.1	75.5	1.89	.7	.76	6.28	.3	120.	5000.	40.
453	.2181	.1272	.0909	58.3	78.9	1.32	.6	.74	4.37	.2	130.	3300.	40.
458	.1936	.1109	.0828	57.3	81.6	.92	.6	.73	3.48	.2	120.	2000.	40.
463	.1658	.0991	.0668	59.7	83.6	1.29	.7	.82	4.50	.3	120.	3200.	30.
468	.2122	.1334	.0788	62.9	79.6	1.08	.7	.82	5.60	.3	110.	4500.	40.
473	.2409	.1599	.0811	66.3	77.1	1.73	.7	.76	6.15	.3	90.	4800.	50.
478	.2183	.1497	.0686	68.6	79.0	1.68	.7	.76	7.73	.3	80.	5000.	50.
483	.2165	.1536	.0628	71.0	79.6	1.77	.8	.77	9.80	.4	80.	5400.	60.
488	.2369	.1649	.0720	69.6	77.9	1.77	.8	.86	8.60	.4	80.	5000.	50.
493	.2397	.1779	.0618	74.2	77.6	1.16	.8	.87	5.30	.5	90.	3300.	50.
498	.3379	.2648	.0731	78.4	69.9	1.08	1.2	.95	4.11	.7	70.	3100.	40.

LITHOLOGY



SEDIMENT ANALYSIS:

3-193 MM. FEBRUARY 1974
198-418 MM. JUNE 1974
423-498 MM. NOVEMBER 1976

Appendix B. Myrtle Lake sediment characteristics.

SEDIMENT ANALYSIS FOR MYRTLE LAKE
CORE OBTAINED: 17 DEC 1973
FROM 6.0 M. OF WATER

SAMPLE DEPTH (MM.)	PARTICULATE MATTER TOTAL	INORGANIC	ORGANIC	WATER	ASH	AUTO-TECH. PHOSPHORUS	E.S. CALCIUM	E.S. ALUMINUM	A.A. IRON	E.S. MAGNESIUM	E.S. ZINC	E.S. MANGANESE	E.S. BORON
	------ GM./CC.		---------	----------		----------	%	----------		----------	-------	PPM	-------
0	.0179	.0080	.0099	98.1	44.8	.21	1.2	.71	.78	.2	390.	500.	30.
24	.0490	.0267	.0223	95.3	54.4	.10	.8	.65	.80	.1	120.	300.	0
51	.0616	.0344	.0272	93.8	55.9	.09	.8	.63	.84	.1	120.	300.	0
75	.0712	.0378	.0334	92.9	53.0	.08	.8	.70	.84	.1	130.	300.	0
99	.0640	.0315	.0325	93.4	49.2	.08	.8	.69	.87	.1	110.	400.	0
123	.0639	.0289	.0350	93.5	45.2	.07	.8	.67	.83	.1	120.	300.	0
150	.0571	.0246	.0324	94.0	43.1	.08	.9	.72	.80	.1	130.	400.	0
174	.0646	.0281	.0365	93.1	43.5	.08	.9	.71	.89	.1	140.	400.	0
201	.0682	.0298	.0384	92.9	43.7	.08	.8	.66	.87	.1	130.	400.	0
225	.0735	.0322	.0413	92.5	43.7	.08	.9	.67	.80	.1	150.	300.	0
249	.0790	.0351	.0439	91.9	44.5	.08	.9	.75	.93	.1	150.	400.	0
298	.0705	.0310	.0395	92.8	44.0	.08	.9	.69	.84	.1	130.	400.	0
346	.0696	.0318	.0379	92.7	45.7	.08	.9	.69	.86	.1	140.	300.	0
394	.0720	.0327	.0393	92.6	45.4	.08	.8	.63	.80	.1	140.	400.	30.
502	.0707	.0313	.0394	92.7	44.2	.08	.8	.64	.93	.1	120.	400.	30.
562	.0720	.0310	.0409	92.6	43.2	.08	.8	.72	.90	.1	180.	400.	30.

SEDIMENT ANALYSIS: NOVEMBER 1975

Appendix C. Pollen counts for Squaw Lake.

NO.	TYPE	DEPTH OF SAMPLE (MM)																
		3	8	13	18	23	28	33	38	43	48	53	58	63	68	73	78	83
1	ABIES	1.	0	1.	0	1.	4.	5.	1.	6.	0	2.	1.	0	2.	2.	2.	6.
2	ACER NEGUNDO	0	0	0	0	0	0	0	0	1.	1.	0	1.	0	0	0	0	0
3	ACER RUBRUM	0	0	1.	1.	0	0	0	1.	0	0	1.	0	0	0	2.	0	0
4	ACER SACCHARINUM-TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	ACER SACCHARUM	1.	2.	1.	2.	1.	0	0	2.	1.	1.	2.	5.	1.	3.	5.	0	2.
6	BETULA	68.	61.	44.	33.	59.	50.	89.	64.	46.	23.	35.	116.	52.	63.	51.	85.	164.
9	CARYA	0	0	0	0	0	0	0	0	0	0	1.	1.	0	0	1.	0	1.
10	CELTIS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	FRAXINUS NIGRA-TYPE	4.	3.	4.	7.	8.	4.	7.	1.	2.	1.	1.	7.	1.	4.	0	3.	6.
12	FRAXINUS PENNSYLVANICA-TYPE	10.	6.	6.	3.	3.	13.	4.	2.	2.	3.	2.	7.	0	5.	3.	2.	3.
14	JUGLANS CINEREA	0	0	0	0	0	0	0	0	0	0	1.	0	0	0	0	1.	0
15	JUGLANS NIGRA	0	0	0	0	0	0	1.	0	0	0	1.	1.	0	0	0	0	1.
16	JUNIPERUS/THUJA	1.	1.	1.	0	1.	1.	0	0	6.	0	1.	4.	0	1.	1.	0	5.
17	LARIX	1.	2.	0	3.	1.	1.	0	3.	2.	1.	4.	2.	0	4.	3.	4.	3.
18	OSTRYA/CARPINUS	7.	5.	5.	2.	2.	5.	8.	13.	2.	1.	1.	16.	5.	9.	14.	16.	8.
19	PICEA	5.	5.	9.	7.	8.	4.	5.	9.	8.	7.	4.	12.	6.	7.	10.	9.	20.
20	PINUS BANKSIANA/RESINOSA-TYPE	86.	83.	70.	63.	72.	86.	95.	132.	106.	88.	96.	242.	127.	143.	145.	110.	194.
21	PINUS STROBUS-TYPE	17.	21.	16.	18.	18.	17.	30.	47.	34.	34.	41.	117.	66.	63.	57.	84.	66.
22	PINUS UNDIFF.	42.	86.	56.	68.	124.	99.	200.	104.	130.	87.	78.	255.	112.	169.	100.	137.	205.
23	POPULUS	18.	15.	21.	15.	13.	28.	32.	21.	16.	16.	17.	95.	13.	17.	17.	28.	48.
24	QUERCUS	37.	24.	36.	29.	32.	39.	38.	28.	25.	9.	20.	49.	23.	37.	28.	37.	44.
25	TILIA	0	0	0	1.	1.	0	1.	1.	1.	1.	2.	1.	0	0	0	1.	0
26	TSUGA	0	0	0	1.	0	0	1.	0	1.	0	0	0	0	0	0	0	0
27	ULMUS	8.	16.	7.	9.	11.	6.	8.	3.	10.	5.	4.	12.	6.	7.	7.	5.	8.
29	CF. PLATANUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	CASTANEA	0	0	0	0	0	0	0	0	0	0	0	1.	0	0	0	0	0
33	PLATANAS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.
34	MORUS	1.	1.	0	0	2.	0	0	0	0	0	0	0	1.	0	0	1.	0
35	ACER SPICATUM	0	0	0	0	0	0	0	0	0	0	0	1.	0	0	0	0	0
36	ALNUS UNDIFF.	46.	29.	38.	21.	23.	24.	54.	48.	43.	16.	21.	64.	23.	23.	22.	24.	55.
39	CEANOTHUS	0	0	0	0	0	1.	0	0	0	0	0	0	0	0	0	0	0
40	CORYLUS	5.	3.	8.	1.	5.	2.	8.	2.	5.	1.	8.	4.	3.	5.	6.	5.	5.
42	ROSACEAE UNDIFF.	0	1.	1.	0	0	0	2.	0	1.	1.	0	1.	0	2.	0	0	1.
43	CF. ROSACEAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	SALIX	9.	6.	6.	8.	10.	10.	14.	17.	6.	5.	2.	12.	3.	9.	1.	5.	8.
46	VITIS	0	0	0	0	0	0	0	0	0	0	0	0	0	2.	0	0	0
47	SARCOBATUS	0	0	0	0	0	0	1.	0	2.	0	0	0	0	0	0	0	0
49	ATHYRIUM	1.	0	0	0	1.	0	0	1.	0	0	1.	0	2.	1.	1.	0	2.
50	DRYOPTERIS-TYPE	0	0	0	1.	1.	0	0	0	0	0	0	1.	0	1.	1.	0	1.
51	EQUISETUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	LYCOPODIUM ANNOTINUM	0	0	0	0	0	0	0	1.	0	0	0	0	0	0	0	0	0
55	POLYPODIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	PTERIDIUM	1.	0	3.	0	1.	2.	5.	2.	0	0	0	5.	1.	1.	3.	8.	6.
57	BOTRYCHIUM MULTIFIDUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	SELAGINELLA RUPESTRIS	0	0	0	1.	1.	4.	0	1.	1.	0	0	0	0	1.	1.	0	0
59	SPHAGNUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.
60	AMBROSIA-TYPE	41.	55.	49.	49.	95.	72.	70.	49.	32.	15.	16.	43.	6.	14.	10.	10.	14.
61	AMORPHA	0	0	0	0	0	0	0	0	0	0	1.	1.	0	3.	0	1.	2.
63	ARTEMISIA	7.	9.	9.	11.	10.	9.	13.	14.	6.	7.	13.	22.	11.	19.	21.	16.	27.
64	TUBULIFLORAE UNDIFF.	4.	7.	5.	0	3.	2.	4.	3.	6.	2.	2.	4.	2.	3.	9.	4.	10.
65	CALTHA PALUSTRIS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

DEPTH OF SAMPLE (MM)

NO.	TYPE	3	8	13	18	23	28	33	38	43	48	53	58	63	68	73	78	83
67	CHENOPODIUM-TYPE	18.	18.	27.	13.	22.	19.	12.	7.	3.	8.	7.	12.	5.	8.	3.	6.	5.
68	EPILOBIUM	0	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	0	0
69	GALIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
71	PLANTAGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	POLYGONUM LAPATHIFOLIUM-TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
73	RUMEX	0	1.	0	0	0	0	0	0	0	1.	0	0	0	0	0	0	0
74	SAGITTARIA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75	SPARGANIUM-TYPE	0	0	1.	1.	0	0	0	0	0	1.	0	0	0	0	0	0	0
76	STELLARIA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	THALICTRUM	1.	1.	0	0	1.	1.	2.	2.	1.	1.	1.	2.	2.	2.	2.	1.	3.
78	TYPHA LATIFOLIA	12.	10.	0	0	0	4.	4.	0	4.	0	0	5.	0	8.	0	2.	0
79	URTICA-TYPE	2.	1.	0	0	1.	0	1.	2.	0	0	1.	0	0	0	0	0	0
82	HYDROPHYLLUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.
83	CF. CUSCUTA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	UMBELLIFERAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	CF. GENTIAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86	EUPHORBIA (CHAMAESYCE)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
87	LEGUMINOSAE UNDIFF.	0	0	0	2.	0	1.	0	0	0	0	0	0	0	0	0	0	0
88	XANTHIUM	0	0	0	0	0	0	0	1.	0	0	0	0	0	0	0	0	0
89	IVA XANTHIFOLIA-TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	IVA CILIATA-TYPE	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	0	0	0
91	RANUNCULACEAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	PETALOSTEMUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	NYMPHAEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95	NUPHAR	0	0	0	1.	0	0	1.	0	0	0	0	0	0	1.	0	0	0
96	POTAMOGETON	2.	2.	3.	2.	1.	2.	1.	3.	2.	1.	1.	5.	1.	0	1.	3.	2.
97	CRUCIFERAE	0	1.	2.	0	0	0	1.	1.	2.	0	0	1.	1.	0	0	0	0
99	HUMULUS/CANNABIS	2.	4.	1.	1.	2.	0	1.	0	1.	0	0	0	1.	3.	0	1.	1.
100	LIGULIFLORAE	0	0	0	1.	0	0	0	0	0	0	0	0	0	0	0	0	0
101	GRAMINAE UNDIFF.	14.	18.	17.	19.	15.	25.	22.	27.	15.	11.	6.	25.	8.	16.	10.	26.	19.
102	CYPERACEAE UNDIFF.	7.	10.	10.	3.	7.	9.	3.	7.	1.	1.	4.	10.	7.	14.	10.	14.	29.
103	ZEA MAYS	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	0	0	0
104	LOSS ON IGNITION	38.	36.	34.	33.	33.	30.	32.	35.	37.	39.	38.	37.	38.	31.	34.	23.	23.
105	INDETERMINATE/OBSCURE	25.	10.	12.	11.	19.	11.	18.	31.	8.	15.	15.	26.	12.	12.	27.	0	21.
106	UNKNOWN	1.	1.	1.	3.	0	0	0	0	3.	0	0	1.	1.	4.	0	16.	2.
107	EUCALYPTUS	1442.	750.	592.	503.	671.	440.	647.	428.	506.	391.	420.	1239.	351.	511.	353.	588.	912.
108	POLYGONUM AVICULARE-TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
109	LYCOPODIUM UNDIFF.	0	0	0	0	0	0	0	1.	0	0	0	0	0	0	0	0	0

DEPTH OF SAMPLE (MM)

NO.	TYPE	88	93	98	103	108	113	118	123	128	133	138	143	148	153	158	163	168
67	CHENOPODIUM-TYPE	10.	6.	3.	6.	6.	3.	5.	3.	2.	1.	1.	6.	1.	2.	3.	3.	1.
68	EPILOBIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
69	GALIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
71	PLANTAGO	0	0	0	0	0	0	0	0	0	0	0	0	1.	0	0	0	0
72	POLYGONUM LAPATHIFOLIUM-TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.	0
73	RUMEX	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	0	0	0
74	SAGITTARIA	0	0	0	0	0	0	0	0	0	0	0	0	1.	0	0	0	0
75	SPARGANIUM-TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	STELLARIA	0	0	0	0	0	0	0	0	0	0	0	1.	0	0	0	0	0
77	THALICTRUM	6.	2.	0	1.	0	1.	3.	0	4.	0	0	0	0	4.	0	2.	0
78	TYPHA LATIFOLIA	0	4.	0	0	0	0	0	4.	0	0	0	0	4.	4.	4.	4.	0
79	URTICA-TYPE	0	0	0	0	0	0	0	0	0	0	1.	0	0	0	1.	0	0
82	HYDROPHYLLUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	CF. CUSCUTA	0	0	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	UMBELLIFERAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.	0	0
85	CF. GENTIAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86	EUPHORBIA (CHAMAESYCE)	0	0	0	0	0	1.	0	0	0	0	0	1.	0	0	0	0	0
87	LEGUMINOSAE UNDIFF.	0	0	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	0
88	XANTHIUM	0	0	0	0	0	0	1.	0	0	1.	0	0	0	0	0	0	0
89	IVA XANTHIFOLIA-TYPE	0	0	0	0	0	0	0	0	1.	0	1.	0	0	0	0	0	0
90	IVA CILIATA-TYPE	0	2.	0	0	0	0	0	0	0	0	1.	0	0	2.	0	0	0
91	RANUNCULACEAE	0	0	0	0	0	1.	0	0	0	0	1.	0	0	0	0	0	0
92	PETALOSTEMUM	0	1.	0	0	0	0	0	0	0	0	0	0	0	1.	0	1.	0
94	NYMPHAEA	0	1.	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	0
95	NUPHAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	POTAMOGETON	2.	4.	1.	1.	0	2.	1.	0	0	0	0	0	1.	1.	2.	0	1.
97	CRUCIFERAE	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
99	HUMULUS/CANNABIS	0	0	0	1.	0	0	0	1.	0	1.	1.	1.	0	0	0	0	0
100	LIGULIFLORAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.	0
101	GRAMINEAE UNDIFF.	21.	19.	7.	16.	13.	11.	15.	14.	13.	13.	5.	9.	11.	13.	22.	18.	15.
102	CYPERACEAE UNDIFF.	16.	12.	8.	9.	9.	9.	4.	6.	2.	13.	10.	8.	6.	5.	11.	10.	9.
103	ZEA MAYS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
104	LOSS ON IGNITION	29.	34.	33.	34.	33.	34.	31.	21.	19.	12.	27.	30.	30.	30.	31.	28.	17.
105	INDETERMINATE/OBSCURE	22.	18.	8.	25.	9.	8.	9.	19.	9.	12.	8.	10.	8.	10.	17.	12.	4.
106	UNKNOWN	1.	4.	0	3.	3.	2.	0	2.	0	0	0	1.	0	4.	2.	0	1.
107	EUCALYPTUS	675.	398.	395.	497.	365.	0	230.	415.	0	511.	337.	506.	268.	368.	0	356.	342.
108	POLYGONUM AVICULARE-TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.	0
109	LYCOPODIUM UNDIFF.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

DEPTH OF SAMPLE (MM)

NO.	TYPE	88	93	98	103	108	113	118	123	128	133	138	143	148	153	158	163	168
1	ABIES	5.	2.	3.	2.	1.	2.	1.	4.	0	5.	2.	2.	1.	1.	4.	1.	1.
2	ACER NEGUNDO	0	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	1.	1.
3	ACER RUBRUM	3.	1.	1.	2.	0	0	1.	0	0	2.	2.	1.	0	0	0	0	1.
4	ACER SACCHARINUM-TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	ACER SACCHARUM	1.	2.	2.	3.	0	0	1.	0	2.	3.	3.	0	1.	2.	1.	0	2.
6	BETULA	127.	45.	93.	75.	37.	44.	48.	48.	71.	57.	74.	107.	53.	56.	90.	102.	47.
9	CARYA	1.	1.	0	0	0	1.	0	0	0	0	0	1.	0	0	1.	1.	0
10	CELTIS	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	FRAXINUS NIGRA-TYPE	1.	5.	2.	2.	2.	5.	7.	4.	4.	5.	6.	3.	1.	2.	3.	7.	1.
12	FRAXINUS PENNSYLVANICA-TYPE	1.	1.	3.	1.	2.	0	1.	3.	1.	0	1.	0	2.	0	1.	0	2.
14	JUGLANS CINEREA	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	JUGLANS NIGRA	0	0	0	0	0	0	1.	0	0	0	1.	0	0	0	0	0	0
16	JUNIPERUS/THUJA	5.	1.	0	2.	1.	1.	2.	2.	0	0	1.	0	0	2.	0	0	2.
17	LARIX	5.	6.	4.	2.	1.	3.	1.	2.	3.	3.	2.	9.	1.	2.	8.	2.	1.
18	OSTRYA/CARPINUS	16.	8.	10.	10.	7.	9.	14.	7.	6.	12.	7.	14.	7.	8.	20.	4.	11.
19	PICEA	23.	4.	3.	13.	3.	7.	3.	4.	1.	4.	7.	4.	4.	3.	9.	9.	7.
20	PINUS BANKSIANA/RESINOSA-TYPE	151.	99.	94.	119.	49.	73.	67.	58.	77.	77.	66.	85.	37.	69.	106.	75.	47.
21	PINUS STROBUS-TYPE	90.	50.	66.	119.	67.	103.	112.	76.	77.	117.	64.	77.	52.	89.	105.	118.	75.
22	PINUS UNDIFF.	211.	87.	107.	217.	51.	62.	78.	75.	102.	80.	66.	79.	57.	67.	90.	141.	132.
23	POPULUS	13.	12.	11.	7.	15.	4.	20.	19.	8.	24.	19.	29.	13.	12.	6.	27.	16.
24	QUERCUS	50.	26.	19.	54.	15.	31.	24.	25.	35.	36.	27.	34.	14.	22.	27.	28.	17.
25	TILIA	1.	1.	0	1.	1.	0	0	1.	0	0	0	0	0	1.	0	1.	1.
26	TSUGA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	ULMUS	5.	8.	4.	9.	4.	5.	5.	7.	6.	4.	1.	7.	3.	2.	8.	7.	4.
29	CF. PLATANUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	CASTANEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	PLATANAS	0	0	1.	0	0	0	0	0	0	0	0	0	0	1.	0	0	1.
34	MORUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	ACER SPICATUM	0	0	0	0	0	0	0	0	0	0	0	0	0	1.	0	0	0
38	ALNUS UNDIFF.	34.	21.	18.	42.	15.	20.	11.	5.	14.	15.	10.	14.	11.	25.	31.	22.	25.
39	CEANOTHUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	CORYLUS	9.	3.	7.	10.	4.	4.	1.	4.	6.	0	5.	3.	0	4.	8.	3.	5.
42	ROSACEAE UNDIFF.	1.	0	0	1.	0	0	1.	1.	0	0	0	2.	0	1.	2.	0	1.
43	CF. ROSACEAE	0	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	SALIX	2.	4.	6.	8.	6.	1.	4.	3.	1.	2.	6.	7.	4.	3.	3.	7.	3.
46	VITIS	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	SARCOBATUS	0	0	1.	0	1.	0	1.	0	1.	0	0	0	0	0	0	0	1.
49	ATHYRIUM	1.	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	0	0
50	DRYOPTERIS-TYPE	1.	0	0	0	1.	0	0	0	0	0	0	0	0	0	0	2.	0
51	EQUISETUM	0	0	0	0	0	0	0	0	0	0	0	0	0	2.	0	0	1.
52	LYCOPODIUM ANNOTINUM	0	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	0	0
55	POLYPODIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	PTERIDIUM	1.	1.	1.	2.	1.	2.	0	0	1.	1.	2.	4.	0	0	1.	1.	1.
57	BOTRYCHIUM MULTIFIDUM	0	0	0	0	0	1.	0	0	0	0	0	0	0	0	0	0	0
58	SELAGINELLA RUPESTRIS	0	0	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	0
59	SPHAGNUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.	0
60	AMBROSIA-TYPE	26.	14.	9.	14.	2.	11.	12.	18.	19.	22.	10.	6.	16.	14.	9.	13.	9.
61	AMORPHA	0	0	2.	0	2.	0	0	0	1.	0	1.	2.	1.	0	1.	0	1.
63	ARTEMISIA	19.	19.	14.	16.	4.	13.	10.	4.	7.	15.	4.	10.	8.	17.	11.	11.	6.
64	TUBULIFLORAE UNDIFF.	5.	1.	4.	4.	4.	2.	2.	1.	2.	2.	1.	4.	1.	6.	6.	2.	5.
65	CALTHA PALUSTRIS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

DEPTH OF SAMPLE (MM)

NO.	TYPE	173	178	183	188	193	198	203	208	213	218	223	258	303	358	403	408	428
1	ABIES	0	2.	2.	1.	2.	1.	5.	0	3.	1.	1.	1.	2.	3.	1.	4.	1.
2	ACER NEGUNDO	0	0	0	0	1.	1.	0	0	1.	0	0	0	0	2.	0	0	0
3	ACER RUBRUM	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.	1.
4	ACER SACCHARINUM-TYPE	0	0	0	0	0	0	0	0	0	0	0	1.	0	0	0	1.	0
5	ACER SACCHARUM	0	0	2.	3.	3.	0	1.	2.	0	1.	1.	0	3.	0	1.	0	0
6	BETULA	30.	47.	44.	89.	42.	34.	65.	65.	58.	59.	47.	42.	77.	33.	32.	48.	44.
9	CARYA	0	0	0	0	0	0	2.	0	0	0	0	0	1.	0	0	0	0
10	CELTIS	0	0	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	FRAXINUS NIGRA-TYPE	1.	1.	3.	5.	6.	6.	3.	3.	3.	4.	4.	2.	10.	3.	1.	1.	4.
12	FRAXINUS PENNSYLVANICA-TYPE	0	2.	2.	4.	0	1.	0	2.	1.	3.	1.	0	3.	1.	0	1.	0
14	JUGLANS CINEREA	1.	0	0	0	0	0	0	1.	0	0	0	0	0	0	0	0	0
15	JUGLANS NIGRA	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	0	0	0
16	JUNIPERUS/THUJA	0	0	1.	3.	2.	0	4.	0	1.	0	0	1.	0	4.	1.	3.	3.
17	LARIX	0	0	3.	3.	4.	2.	2.	1.	2.	1.	5.	0	4.	2.	2.	6.	0
18	OSTRYA/CARPINUS	10.	8.	16.	25.	14.	14.	18.	19.	10.	18.	12.	7.	8.	6.	8.	6.	17.
19	PICEA	25.	9.	2.	13.	9.	4.	7.	6.	8.	4.	8.	1.	7.	7.	8.	1.	3.
20	PINUS BANKSIANA/RESINOSA-TYPE	49.	73.	29.	81.	63.	92.	71.	39.	58.	53.	77.	23.	45.	18.	0	35.	40.
21	PINUS STROBUS-TYPE	54.	82.	53.	101.	106.	122.	155.	108.	80.	86.	98.	45.	106.	90.	0	137.	128.
22	PINUS UNDIFF.	123.	98.	113.	178.	109.	114.	136.	116.	113.	151.	153.	115.	138.	66.	206.	70.	87.
23	POPULUS	8.	14.	6.	10.	8.	5.	8.	6.	6.	3.	5.	8.	51.	5.	8.	6.	17.
24	QUERCUS	22.	15.	18.	51.	25.	21.	37.	27.	32.	23.	38.	13.	24.	10.	25.	20.	26.
25	TILIA	0	0	1.	0	0	1.	0	2.	0	0	1.	0	0	1.	1.	0	0
26	TSUGA	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	0	0	0
27	ULMUS	1.	4.	7.	6.	5.	5.	5.	5.	3.	1.	6.	5.	6.	3.	4.	2.	3.
29	CF. PLATANUS	0	0	0	1.	0	0	0	0	0	0	0	0	0	0	0	0	0
32	CASTANEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	PLATANAS	0	0	1.	0	0	0	0	0	0	1.	0	0	0	0	0	0	0
34	MORUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	ACER SPICATUM	0	0	0	0	1.	0	0	0	0	0	0	0	0	0	1.	0	0
38	ALNUS UNDIFF.	13.	21.	20.	23.	23.	23.	25.	19.	16.	25.	30.	12.	11.	11.	9.	23.	12.
39	CEANOTHUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	CORYLUS	3.	4.	3.	3.	6.	4.	4.	2.	2.	3.	4.	2.	3.	3.	3.	3.	5.
42	ROSACEAE UNDIFF.	0	0	0	1.	0	0	0	1.	0	0	1.	1.	0	0	1.	0	0
43	CF. ROSACEAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	SALIX	1.	5.	5.	5.	10.	2.	3.	3.	6.	1.	3.	1.	6.	3.	0	4.	3.
46	VITIS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	SARCOBATUS	2.	0	0	3.	0	2.	2.	0	0	0	0	0	0	0	1.	0	1.
49	ATHYRIUM	0	1.	0	2.	0	0	0	0	0	0	0	0	0	0	0	0	0
50	DRYOPTERIS-TYPE	0	0	0	0	0	0	1.	0	0	0	0	2.	1.	1.	0	0	1.
51	EQUISETUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	LYCOPODIUM ANNOTINUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	POLYPODIUM	0	0	0	0	0	1.	0	0	0	0	0	0	0	0	0	0	0
56	PTERIDIUM	2.	1.	5.	9.	3.	5.	2.	1.	1.	2.	1.	1.	2.	0	0	2.	2.
57	BOTRYCHIUM MULTIFIDUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	SELAGINELLA RUPESTRIS	1.	0	0	0	1.	0	0	0	0	0	0	0	0	1.	0	0	0
59	SPHAGNUM	2.	0	1.	1.	0	0	2.	0	0	0	0	1.	0	0	0	0	1.
60	AMBROSIA-TYPE	15.	6.	5.	20.	11.	4.	15.	8.	12.	11.	6.	5.	8.	8.	3.	2.	2.
61	AMORPHA	0	2.	0	0	0	1.	0	0	0	0	1.	0	4.	0	0	0	3.
63	ARTEMISIA	11.	13.	10.	25.	16.	13.	10.	12.	10.	12.	14.	8.	10.	8.	5.	12.	11.
64	TUBULIFLORAE UNDIFF.	2.	4.	6.	8.	6.	3.	10.	3.	2.	7.	7.	4.	2.	3.	2.	3.	1.
65	CALTHA PALUSTRIS	0	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

DEPTH OF SAMPLE (MM)

NO.	TYPE	173	178	183	188	193	198	203	208	213	218	223	258	303	358	403	408	428
67	CHENOPODIUM-TYPE	1.	4.	2.	4.	2.	3.	6.	0	3.	4.	9.	0	1.	4.	3.	5.	3.
68	EPILOBIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
69	GALIUM	0	0	0	0	0	1.	0	0	0	0	0	0	0	0	0	0	0
71	PLANTAGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	POLYGONUM LAPATHIFOLIUM-TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
73	RUMEX	0	0	0	0	0	1.	0	0	0	0	1.	0	1.	0	0	1.	0
74	SAGITTARIA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75	SPARGANIUM-TYPE	0	1.	1.	0	0	0	0	0	0	0	1.	0	0	0	0	0	0
76	STELLARIA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	THALICTRUM	0	2.	0	1.	3.	2.	0	1.	0	1.	0	0	1.	0	0	0	0
78	TYPHA LATIFOLIA	0	0	8.	2.	4.	0	0	0	0	0	4.	0	4.	0	0	0	0
79	URTICA-TYPE	0	1.	0	0	0	0	0	1.	0	0	0	0	0	0	0	0	0
82	HYDROPHYLLUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	CF. CUSCUTA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	UMBELLIFERAE	0	1.	0	0	0	1.	0	0	0	0	0	0	0	0	0	0	0
85	CF. GENTIAN	0	0	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86	EUPHORBIA (CHAMAESYCE)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
87	LEGUMINOSAE UNDIFF.	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
88	XANTHIUM	0	0	0	1.	1.	0	0	0	0	0	0	0	0	0	0	0	0
89	IVA XANTHIFOLIA-TYPE	0	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	IVA CILIATA-TYPE	0	0	0	2.	0	0	0	0	0	0	0	0	0	0	0	0	0
91	RANUNCULACEAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	PETALOSTEMUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	NYMPHAEA	0	0	0	0	0	0	1.	0	0	0	0	0	0	0	0	0	0
95	NUPHAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.	0
96	POTAMOGETON	0	1.	0	1.	1.	0	3.	2.	2.	0	2.	0	1.	0	1.	0	0
97	CRUCIFERAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
99	HUMULUS/CANNABIS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	LIGULIFLORAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
101	GRAMINAE UNDIFF.	9.	12.	12.	28.	22.	19.	10.	21.	12.	9.	15.	7.	14.	6.	6.	6.	8.
102	CYPERACEAE UNDIFF.	7.	16.	9.	14.	8.	10.	6.	8.	7.	2.	9.	7.	4.	8.	4.	6.	6.
103	ZEA MAYS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
104	LOSS ON IGNITION	17.	25.	30.	26.	21.	20.	24.	20.	21.	26.	27.	11.	36.	19.	41.	40.	34.
105	INDETERMINATE/OBSCURE	6.	12.	4.	10.	13.	8.	13.	12.	14.	10.	22.	11.	8.	7.	11.	4.	3.
106	UNKNOWN	0	1.	0	3.	1.	1.	3.	0	1.	2.	7.	0	0	2.	0	0	0
107	EUCALYPTUS	326.	254.	228.	421.	307.	324.	337.	299.	264.	234.	0	290.	322.	211.	0	138.	199.
108	POLYGONUM AVICULARE-TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
109	LYCOPODIUM UNDIFF.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

DEPTH OF SAMPLE (MM)

NO.	TYPE	453	458	478	498	653
1	ABIES	2.	2.	1.	4.	6.
2	ACER NEGUNDO	0	0	0	1.	0
3	ACER RUBRUM	1.	0	0	1.	0
4	ACER SACCHARINUM-TYPE	0	0	0	0	0
5	ACER SACCHARUM	1.	1.	0	2.	1.
6	BETULA	57.	29.	30.	68.	56.
9	CARYA	0	0	0	0	0
10	CELTIS	0	0	0	0	0
11	FRAXINUS NIGRA-TYPE	6.	3.	1.	4.	3.
12	FRAXINUS PENNSYLVANICA-TYPE	3.	3.	1.	1.	4.
14	JUGLANS CINEREA	0	0	0	0	0
15	JUGLANS NIGRA	0	0	0	0	0
16	JUNIPERUS/THUJA	0	0	2.	1.	1.
17	LARIX	4.	4.	0	0	2.
18	OSTRYA/CARPINUS	6.	11.	5.	10.	16.
19	PICEA	7.	3.	1.	3.	6.
20	PINUS BANKSIANA/RESINOSA-TYPE	0	51.	22.	51.	27.
21	PINUS STROBUS-TYPE	0	179.	82.	188.	126.
22	PINUS UNDIFF.	385.	107.	91.	103.	96.
23	POPULUS	20.	8.	8.	14.	8.
24	QUERCUS	22.	24.	14.	47.	22.
25	TILIA	0	0	0	1.	1.
26	TSUGA	0	0	0	0	0
27	ULMUS	2.	4.	4.	4.	5.
29	CF. PLATANUS	0	0	0	0	0
32	CASTANEA	0	0	0	0	0
33	PLATANAS	1.	1.	0	0	0
34	MORUS	0	0	0	0	0
35	ACER SPICATUM	0	0	0	0	0
38	ALNUS UNDIFF.	13.	9.	10.	23.	23.
39	CEANOTHUS	0	0	0	0	0
40	CORYLUS	1.	2.	2.	4.	6.
42	ROSACEAE UNDIFF.	0	0	1.	0	1.
43	CF. ROSACEAE	0	0	0	0	0
44	SALIX	1.	1.	1.	7.	7.
46	VITIS	0	0	0	0	0
47	SARCOBATUS	1.	1.	1.	0	0
49	ATHYRIUM	0	1.	0	0	0
50	DRYOPTERIS-TYPE	1.	0	0	2.	0
51	EQUISETUM	1.	0	0	0	1.
52	LYCOPODIUM ANNOTINUM	0	0	0	0	0
55	POLYPODIUM	0	0	0	0	0
56	PTERIDIUM	0	0	1.	1.	0
57	BOTRYCHIUM MULTIFIDUM	0	0	0	0	0
58	SELAGINELLA RUPESTRIS	0	0	0	0	0
59	SPHAGNUM	1.	0	0	0	0
60	AMBROSIA-TYPE	4.	5.	1.	7.	8.
61	AMORPHA	0	1.	0	0	0
63	ARTEMISIA	12.	6.	6.	18.	15.
64	TUBULIFLORAE UNDIFF.	3.	4.	2.	4.	6.
65	CALTHA PALUSTRIS	0	0	0	0	0

DEPTH OF SAMPLE (MM)

NO.	TYPE	453	458	478	498	653
67	CHENOPODIUM-TYPE	3.	1.	3.	2.	5.
68	EPILOBIUM	0	0	0	0	0
69	GALIUM	0	0	0	0	0
71	PLANTAGO	0	0	0	0	0
72	POLYGONUM LAPATHIFOLIUM-TYPE	0	0	0	0	0
73	RUMEX	0	0	0	0	0
74	SAGITTARIA	0	0	0	0	0
75	SPARGANIUM-TYPE	0	0	0	0	0
76	STELLARIA	0	0	0	0	0
77	THALICTRUM	1.	2.	2.	1.	1.
78	TYPHA LATIFOLIA	0	0	0	0	0
79	URTICA-TYPE	0	1.	0	0	0
82	HYDROPHYLLUM	0	0	0	0	0
83	CF. CUSCUTA	0	0	0	0	0
84	UMBELLIFERAE	0	0	0	0	0
85	CF. GENTIAN	0	0	0	0	0
86	EUPHORBIA (CHAMAESYCE)	0	0	0	0	0
87	LEGUMINOSAE UNDIFF.	0	1.	0	2.	0
88	XANTHIUM	0	0	0	0	0
89	IVA XANTHIFOLIA-TYPE	0	0	0	0	0
90	IVA CILIATA-TYPE	0	0	0	0	0
91	RANUNCULACEAE	0	0	0	0	0
92	PETALOSTEMUM	0	0	0	0	0
94	NYMPHAEA	0	0	0	0	1.
95	NUPHAR	0	0	0	0	0
96	POTAMOGETON	0	0	0	0	2.
97	CRUCIFERAE	0	0	0	1.	0
99	HUMULUS/CANNABIS	1.	0	0	0	0
100	LIGULIFLORAE	0	0	0	0	0
101	GRAMINAE UNDIFF.	15.	9.	3.	10.	16.
102	CYPERACEAE UNDIFF.	9.	6.	4.	5.	5.
103	ZEA MAYS	0	0	0	0	0
104	LOSS ON IGNITION	42.	43.	31.	22.	0
105	INDETERMINATE/OBSCURE	8.	7.	5.	3.	13.
106	UNKNOWN	3.	0	0	1.	1.
107	EUCALYPTUS	0	112.	122.	289.	238.
108	POLYGONUM AVICULARE-TYPE	0	0	0	0	0
109	LYCOPODIUM UNDIFF.	0	0	0	0	0

Appendix D. Pollen counts for Myrtle Lake.

DEPTH OF SAMPLE (MM)

NO.	TYPE	1	25	52	76	100	124	151	175	202	226	250	301	349	397	448	508	568
1	ABIES	0	1.	1.	0	0	1.	1.	1.	2.	0	2.	3.	0	1.	0	1.	0
2	ACER NEGUNDO	0	2.	0	0	0	0	0	0	0	0	1.	0	0	1.	0	0	0
3	ACER RUBRUM	1.	0	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	ACER SACCHARINUM-TYPE	0	0	0	0	0	0	1.	0	0	0	0	0	0	1.	0	0	0
5	ACER SACCHARUM	2.	0	0	3.	1.	1.	0	0	3.	1.	2.	1.	1.	1.	1.	1.	0
6	BETULA	114.	58.	48.	49.	31.	39.	51.	39.	53.	40.	49.	39.	26.	43.	38.	40.	33.
7	CF. ACER RUBRUM	0	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	0	0
9	CARYA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.	0
11	FRAXINUS NIGRA-TYPE	9.	1.	4.	4.	1.	2.	1.	5.	2.	6.	6.	1.	4.	2.	1.	3.	2.
12	FRAXINUS PENNSYLVANICA-TYPE	3.	4.	2.	3.	2.	0	1.	0	0	0	3.	0	0	1.	0	3.	0
14	JUGLANS CINEREA	0	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	0	0
15	JUGLANS NIGRA	0	0	0	0	1.	0	0	0	0	0	0	0	0	0	0	0	0
16	JUNIPERUS/THUJA	3.	3.	1.	1.	0	2.	3.	0	0	0	1.	3.	2.	1.	0	2.	3.
17	LARIX	1.	1.	1.	5.	1.	7.	8.	1.	6.	3.	4.	3.	2.	4.	4.	5.	2.
18	OSTRYA/CARPINUS	0	4.	2.	7.	3.	1.	8.	3.	5.	11.	6.	4.	8.	6.	14.	7.	3.
19	PICEA	3.	3.	3.	10.	5.	3.	4.	2.	8.	4.	3.	4.	5.	5.	9.	8.	5.
20	PINUS BANKSIANA/RESINOSA-TYPE	84.	85.	79.	128.	93.	132.	118.	108.	94.	96.	124.	77.	66.	89.	84.	86.	45.
21	PINUS STROBUS-TYPE	26.	26.	29.	52.	48.	76.	54.	52.	81.	56.	63.	54.	51.	59.	60.	63.	41.
22	PINUS UNDIFF.	52.	53.	62.	90.	86.	109.	113.	81.	128.	80.	134.	77.	51.	90.	70.	83.	67.
23	POPULUS	39.	4.	16.	11.	20.	20.	24.	21.	10.	16.	16.	16.	12.	19.	10.	21.	16.
24	QUERCUS	41.	26.	27.	19.	10.	20.	14.	28.	21.	17.	15.	9.	15.	21.	12.	11.	12.
25	TILIA	0	0	0	1.	0	1.	0	0	0	1.	0	0	1.	0	0	0	0
26	TSUGA	0	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	1.	0
27	ULMUS	7.	10.	4.	5.	9.	4.	1.	3.	2.	4.	9.	4.	1.	5.	2.	4.	3.
28	CF. ACER NEGUNDO	0	0	0	0	0	0	1.	0	0	0	0	0	0	0	0	0	0
30	LIQUIDAMBAR	0	0	0	0	0	0	0	0	0	0	0	1.	0	0	0	0	0
31	MACLURA	0	0	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	CASTANEA	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	0	0	0
33	PLATANAS	0	0	0	0	0	0	1.	1.	0	0	0	0	0	0	0	1.	0
34	MORUS	0	1.	0	1.	0	0	1.	0	0	0	0	0	0	1.	0	0	0
36	ALNUS CRISPA-TYPE	0	0	0	0	0	0	0	0	0	5.	0	0	0	0	0	0	0
38	ALNUS UNDIFF.	52.	33.	6.	35.	24.	31.	31.	32.	41.	35.	30.	21.	19.	32.	14.	21.	16.
40	CORYLUS	10.	6.	0	3.	1.	4.	1.	1.	4.	3.	4.	2.	5.	4.	6.	3.	2.
41	RHUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.	0
42	ROSACEAE UNDIFF.	1.	0	0	0	2.	2.	2.	1.	3.	0	0	0	1.	0	0	1.	1.
44	SALIX	4.	2.	5.	15.	8.	11.	7.	6.	5.	7.	4.	3.	4.	7.	3.	4.	0
45	ERICACEAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.	0
46	VITIS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.	0	0
47	SARCOBATUS	0	0	0	0	1.	2.	2.	1.	0	0	0	0	1.	0	0	2.	0
48	EPHEDRA VIRIDIS-TYPE	0	0	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	0
49	ATHYRIUM	0	2.	0	1.	0	0	0	1.	0	3.	0	0	0	0	1.	0	0
50	DRYOPTERIS-TYPE	0	0	2.	2.	0	5.	1.	1.	1.	1.	2.	5.	0	3.	1.	1.	3.
51	EQUISETUM	1.	0	0	0	0	1.	0	0	1.	0	0	0	0	0	0	0	0
54	LYCOPODIUM COMPLANATUM-TYPE	0	0	0	0	0	0	0	1.	1.	0	0	0	0	0	0	0	0
56	PTERIDIUM	1.	1.	1.	5.	1.	9.	3.	7.	1.	4.	5.	3.	3.	1.	4.	5.	4.
57	BOTRYCHIUM MULTIFIDUM	0	0	0	0	0	0	0	1.	0	0	0	0	0	0	0	0	0
58	SELAGINELLA RUPESTRIS	0	0	0	1.	0	0	0	0	1.	0	1.	0	0	0	0	0	0
59	SPHAGNUM	0	0	0	1.	0	0	0	0	1.	0	2.	1.	0	1.	0	0	1.
60	AMBROSIA-TYPE	36.	28.	37.	38.	23.	19.	16.	17.	28.	18.	16.	10.	8.	12.	7.	7.	9.
61	AMORPHA	0	0	0	0	1.	1.	1.	0	0	0	0	1.	0	0	0	0	0
62	CF. AMORPHA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.	0

		DEPTH OF SAMPLE (MM)																
NO.	TYPE	1	25	52	76	100	124	151	175	202	226	250	301	349	397	448	508	568
63	ARTEMISIA	10.	6.	6.	10.	15.	14.	7.	11.	12.	9.	17.	11.	7.	7.	6.	7.	5.
64	TUBULIFLORAE UNDIFF.	4.	1.	0	2.	1.	2.	5.	4.	3.	2.	6.	6.	3.	3.	2.	1.	5.
65	CALTHA PALUSTRIS	0	0	0	0	0	0	0	0	0	0	0	0	1.	0	0	0	0
66	CAMPANULA	0	0	0	0	0	0	0	0	0	0	0	0	1.	0	0	0	0
67	CHENOPODIUM-TYPE	11.	9.	9.	19.	6.	9.	8.	5.	8.	7.	4.	7.	3.	4.	2.	0	2.
69	GALIUM	0	0	0	1.	0	0	1.	0	0	0	0	0	1.	0	0	1.	0
72	POLYGONUM LAPATHIFOLIUM-TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	2.	1.	0	0
73	RUMEX	0	0	0	2.	0	0	0	0	0	0	0	0	0	0	0	0	0
75	SPARGANIUM-TYPE	2.	1.	0	1.	0	1.	0	0	0	0	0	0	0	2.	1.	0	0
77	THALICTRUM	0	1.	0	1.	2.	1.	1.	0	0	1.	2.	2.	0	1.	1.	1.	2.
78	TYPHA LATIFOLIA	0	0	3.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	URTICA-TYPE	0	2.	0	1.	0	0	0	0	0	0	0	0	0	0	0	1.	0
80	STACHYS PALUSTRIS	0	0	0	0	0	0	0	0	0	0	0	1.	0	0	0	0	0
81	CF. LYSIMACHIA THYRSIFLORA	0	0	0	0	0	0	0	0	0	0	0	0	0	1.	0	0	0
87	LEGUMINOSAE UNDIFF.	0	1.	1.	2.	0	0	0	0	0	0	0	0	0	0	0	0	0
88	XANTHIUM	1.	0	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	IVA CILIATA-TYPE	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.
93	BRASENIA	0	0	0	0	0	0	1.	0	0	2.	1.	0	0	1.	0	0	0
94	NYMPHAEA	0	0	0	0	2.	2.	1.	0	3.	0	0	11.	1.	5.	3.	1.	3.
95	NUPHAR	0	1.	1.	0	1.	1.	2.	2.	1.	1.	1.	0	0	1.	0	0	0
96	POTAMOGETON	1.	2.	2.	1.	6.	3.	4.	0	0	1.	4.	3.	1.	1.	1.	5.	4.
97	CRUCIFERAE	0	1.	6.	0	0	0	0	0	1.	0	0	2.	0	0	0	0	0
98	IMPATIENS CAPENSIS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.
99	HUMULUS/CANNABIS	0	1.	0	2.	0	0	0	0	1.	0	0	1.	0	1.	0	0	0
100	LIGULIFLORAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.	0
101	GRAMINAE UNDIFF.	17.	23.	15.	12.	18.	23.	14.	14.	18.	12.	11.	13.	5.	17.	9.	13.	4.
102	CYPERACEAE UNDIFF.	6.	17.	9.	11.	7.	19.	8.	13.	13.	12.	15.	16.	12.	14.	11.	18.	10.
103	ZEA MAYS	1.	0	0	0	0	0	0	0	0	0	0	0	0	1.	0	0	0
104	LOSS ON IGNITION	55.	46.	44.	47.	51.	55.	57.	57.	56.	56.	56.	56.	54.	55.	0	56.	57.
105	INDETERMINATE/OBSCURE	18.	8.	16.	5.	5.	8.	2.	12.	6.	5.	5.	2.	3.	3.	14.	13.	0
106	UNKNOWN	0	1.	1.	4.	1.	0	2.	1.	2.	1.	2.	1.	1.	4.	1.	1.	2.
107	EUCALYPTUS	1035.	463.	358.	437.	295.	439.	355.	289.	385.	226.	342.	196.	202.	278.	238.	241.	166.

Appendix E. Vegetation plot descriptions.

Plot	Direction/distance from datum*	T.-R.-Sec.	40 or lot	Elevation (ft)	Slope (%)	Aspect (°T.)	Position on slope
A	246°T./2920'	43-36-6	NW/NE	1642	3	060	middle
B	218°T./4510'	43-36-6	NW-SE	1635	8	218	top
C	210°T./2350'	43-36-6	SE/NE	1650	9	044	top
D	250°T./335'	43-36-6	lot 1	1672	4	339	upper 1/3
E	264°T./2510'	43-36-6	lot 2	1675	8	214	middle
F	194°T./2540'	43-36-6	SE/NE	1610	--	---	middle
G	266°T./910'	43-36-6	lot 1	1679	3	050	upper 1/3
H	239°T./3270'	43-36-6	SW-NE	1661	13	060	lower 1/3
I	195°T./3225'	43-36-6	lot 8	1580	--	---	middle
J	265°T./3160'	43-36-6	lot 3	1662	3	239	middle
K	235°T./2970'	43-36-6	SW-NE	1651	4	314	upper 1/3
L	192°T./1030'	43-36-6	lot 4	1672	2	155	middle
M	248°T./3580'	43-36-6	SE/NW	1675	13	234	middle
N	228°T./3275'	43-36-6	SW/NE	1678	7	052	top
P	236°T./2435'	43-36-6	SW/NE	1641	11	244	lower 1/3
Q	224°T./4140'	43-36-6	NW/SE	1651	6	218	middle
R3	157°T./1900'	43-36-5	lot 5	1570	5	138	top
R4	347°T./1000'	44-36-31	NE/SE	1635	--	---	middle
S	236°T./4180'	43-36-6	SE/NW	1654	8	334	lower 1/3
T	241°T./3975'	43-36-6	SE/NW	1668	11	334	upper 1/3
U	205°T./4030'	43-36-6	NW/SE	1625	4	120	top
V	211°T./4490'	43-36-6	NW/SE	1639	8	213	middle
W	226°T./3725'	43-36-6	SW/NE	1668	3	088	middle
X	212°T./4285'	43-36-6	NW/SE	1642	13	287	lower 1/3
Y	223°T./960'	43-36-5	lot 5	1682	6	220	top
Z	------------	43-36-5	lot 7	1590	--	---	upper 1/3

*, datum is a mature red pine on the North Boundary Road, east of the NE corner, Sec. 6.

Appendix F. Stump data summary, 1973.

Plot	Species		No. of Stumps	Plot Total
			-------(# per .1 acre)--------	
A	*Populus tremuloides*		15	
	Salix spp.		1	16
B	*Populus tremuloides*		2	
	Pinus banksiana		5	7
C	*Pinus* undifferentiated		9	
	Betula papyrifera		8	
	Pinus resinosa		2	19
D	*Pinus* undifferentiated		2	
	Populus tremuloides		11	
	Amelanchier sp.		1	
	Salix spp.		3	17
E	*Populus tremuloides*		5	
	Salix spp.		17	
	Prunus pensylvanica		3	
	Pinus undifferentiated		1	26
G	*Quercus macrocarpa*		1	
	Pinus undifferentiated	F,C	7	
	Betula papyrifera		1	
	Populus tremuloides		1	10
H	*Populus tremuloides*		5	
	Prunus virginiana		1	
	Amelanchier sp.		1	7
J	*Pinus banksiana*		7	
	Populus tremuloides		1	8
K	*Pinus* undifferentiated	F,C	2	
	Salix spp.		3	
	Alnus rugosa		3	
	Populus tremuloides		3	
	Prunus virginiana		1	12
L	*Populus tremuloides*		6	
	Pinus undifferentiated	F,C	3	9
M	*Betula papyrifera*		1	
	Pinus undifferentiated	F,C	4	5
N	*Betula papyrifera*		2	
	Populus tremuloides		6	
	Pinus undifferentiated	F	1	9

Appendix F. Continued.

Plot	Species	No. of Stumps	Plot Total
		-------(# per .1 acre)-------	
P	_Populus tremuloides_	4	
	Alnus rugosa	8	
	Salix humilis	8	20
Q	_Pinus_ undifferentiated F	2	
	Populus tremuloides	4	6
R3	_Pinus resinosa_ F,C	11	
	Betula papyrifera	1	12
S	_Populus tremuloides_	2	
	Alnus rugosa	1	
	Salix humilis	6	9
T	_Salix humilis_	5	5
U	_Pinus_ undifferentiated F	3	
	Salix humilis	11	
	Pinus resinosa	1	
	Betula papyrifera	1	16
V	_Populus tremuloides_	19	19
W	_Pinus banksiana_	15	15
X	_Populus tremuloides_	4	
	Salix humilis	2	
	Pinus banksiana	1	
	Prunus virginiana	1	8
Y	_Populus tremuloides_	3	
	Betula papyrifera	1	
	Pinus undifferentiated F	1	5
Z[a]	_Populus tremuloides_	3	
	Pinus resinosa C	1	
	Prunus serotina	1	5

[a] values for plot Z are per .01 acre
F indicates fire evidence
C indicates cutting evidence

Appendix G. Soil physical data.

Stand	Horizon	Width (in)	Moisture %	O.M.	Sand	Silt	Clay	Texture	dB gm/cc	Cobbles >2 mm. %	Color	Mottles	Roots	Notes
				---------% o.d.w.--------										
A	AO	1.0	---	---	---	---	---	---	----	--	red	-	-	
	A1	1.5	43.5	20.6	---	---	---	---	----	<15	black	-	***	
	B1	8.5	10.2	0.8	61.0	34.0	5.0	sl	1.36	<15	tan	-	**	
	B2	6.5	8.7	0.6	65.0	29.0	6.0	sl	1.54	<15	gray/brown	-	-	
	B3	16.5	11.1	0.8	59.5	27.5	13.0	sl	1.92	19	tan	+	*	
	C	----	8.0	1.2	57.0	25.0	18.0	sl	2.00	47	----	---	-	cemented
	total depth of pit:37"													
D	AO	.8	---	---	---	---	----	---	----	--	----	-	-	
	A1	1.3	---	---	---	---	---	---	----	--	----	-	***	
	A2	9.0	9.5	0.9	64.5	30.5	5.0	sl	1.58	<15	tan	-	**	
	B1	10.0	8.5	0.6	66.5	26.5	7.0	sl	1.77	28	gray/tan	+	**	
	B2	18.5	14.0	1.4	60.0	23.0	17.0	sl	1.89	38	tan	+	*	clay
	C1	2.0	---	---	---	---	---	---	----	--	----	-	-	
	C2	8.0	11.3	0.6	81.0	6.0	13.0	sl	1.70	<15	red	-	*	sand
	C3	----	15.8	1.6	32.5	43.5	24.0	l	----	48	gray	-	**	cemented
	total depth of pit:44"													
E	AO	1.8	---	---	---	---	---	---	----	--	----	-	-	
	A1	1.5	58.2	30.0	---	---	---	---	----	<15	black	-	***	
	A2	3.0	14.8	10.1	55.5	40.5	4.0	l	1.09	<15	gray	-	**	
	B1	4.8	11.5	1.3	54.5	38.5	7.0	sl	1.81	25	tan	-	**	
	B2	9.0	14.1	0.7	46.5	46.5	7.0	sl	1.62	<15	gray/red	+	**	
	B3/C1	18.0	9.5	1.4	62.0	24.5	13.5	sl-l	1.69	21	red/gray	+	**	
	C1/C2	----	---	---	---	---	---	---	----	--	red/gray	+	*	cemented
	total depth of pit:46"													
G	AO	----	---	---	---	---	---	---	----	--	----	-	-	
	A1	1.5	69.0	21.5					.29	<15	black	-	***	
	A2	1.5	12.0	2.0	69.5	25.5	5.0	sl	1.17	<15	gray	-	**	
	B1	2.8	8.5	0.8	76.0	18.5	5.5	ls	1.33	<15	tan	-	**	
	B2	14.8	8.9	0.7	88.0	6.0	6.0	s-ls	1.75	25	tan	+	*	
	B3	12.5	10.8	0.7	86.0	9.0	5.0	ls	1.77	20	tan	+	-	
	C1	9.0	4.4	0.5	93.0	3.0	4.0	s	----	<15	yellow	-	-	sand
	C2	----	---	---	---	---	---	---	----	--	----	-	-	
	total depth of pit:59"													
J	AO	2.0	---	---	---	---	---	---	----	--	red/brown	-	-	
	A1	2.3	52.9	18.0	---	---	---	---	.30	<15	black	-	***	
	A2	4.0	10.1	2.5	63.0	31.0	6.0	sl	.82	20	tan	-	**	
	B1	14.0	8.3	0.6	66.0	28.0	6.0	sl	1.69	<15	tan/gray	+	*	
	B2	20.0	12.9	1.4	60.0	27.0	12.5	sl	1.89	23	red/gray	+	*	
	C	----	11.8	1.4	61.5	21.5	17.0	sl	----	--	red	-	*	
	total depth of pit:50"													
L	AO	1.0	---	---	---	---	---	---	----	--	red	-	-	
	A1	1.5	---	---	---	---	---	---	----	--	black	-	***	
	A2	6.5	13.0	1.0	31.0	56.5	12.0	sil	1.54	<15	gray/white	-	*	
	B2	17.0	16.3	2.0	18.0	57.0	25.0	sil	1.66	47	tan/orange	-	**	crumb
	B3	9.0	---	---	---	---	---	---	----	--	tan/white	-	*	
	C	----	8.4	1.3	77.5	10.5	12.0	sl	1.63	42	tan	-	*	sand&pebbles
	total depth of pit:38.5"													

Appendix G. Continued.

Stand	Horizon	Width (in)	Moisture %	O.M.	Sand	Silt	Clay	Texture	dB gm/cc	Cobbles >2 mm. %	Color	Mottles	Roots	Notes
				---------% o.d.w.--------										
M	A0	----	---	---	---	---	---	---	----	--	----	-	-	
	A1	.8	84.2	27.1	---	---	---	---	.38	<15	black	-	***	
	B1	6.0	12.6	1.0	59.5	34.5	6.0	sl	1.60	<15	gray	-	**	
	B2	10.0	10.4	0.7	71.5	20.0	8.5	sl	1.60	30	gray/tan	+		
	B3/C1	15.0	11.0	1.8	61.0	18.5	20.5	sl	1.98	42	tan	-	*	
	total depth of pit:42"													
R3	A0	2.3	---	---	---	---	---	---	----	--	----	-	-	
	A1	1.0	---	---	---	---	---	---	----	--	gray/black	-	**	
	A2	4.5	4.4	1.8	85.0	11.5	4.5	ls	1.42	<15	gray	-	**	
	B2	11.0	8.0	1.2	79.0	16.0	5.0	ls	1.66	27	tan	-	**	
	B3	9.0	8.0	1.4	65.5	22.0	12.5	sl	2.05	18	gray/tan	-	*	
	C1	----	8.8	1.4	67.0	17.0	16.0	sl	1.80	34	tan/gray	-	*	
	total depth of pit:43"													
R4	A	14.0	1.6	0.3	83.0	12.0	5.0	ls	1.82	33	tan/gray	-	**	
	B	31.0	2.2	0.6	78.0	15.0	7.0	ls	1.62	18	brown red	+	*	
	C	----	3.1	1.4	84.0	11.0	5.0	ls	1.49	<15	tan	+	*	
	total depth of pit:50"													
Z	A0	1.2	---	---	---	---	---	---	----	--	black	-	-	
	A1	2.0	---	---	---	---	---	---	----	--	black/tan	-	**	
	A2	8.8	5.0	1.2	47.0	42.5	8.5	l	1.46	<15	tan	-	*	
	B	12.5	3.7	1.2	50.0	43.0	7.0	l	----	<15	tan	+	*	
	C	----	2.8	1.2	63.5	25.7	10.8	sl	1.74	<15	brown/gray	+	-	cemented
	total depth of pit:35"													

Notes: O.M. indicates organic matter
--- indicates no observation made
*** indicates many roots
** indicates moderate amount of roots
* indicates few roots

dB indicates bulk density
Moisture is expressed as % wet weight

Appendix H. Soil chemical data.

Plot	Horizon	Calcium	Magnesium	Sodium	Potassium	Hydrogen	C.E.C.	Kjeldahl Nitrogen %	Extractable Phosphorus ppm	Total Phosphorus ppm	pH	Cond. Mmho/cm^2
		meq/100 gm										
A	A1	18.68	2.25	0.05	0.40	5.96	27.34	0.493	56.8	678	5.1	672
	B1	1.32	0.42	0.01	0.51	1.81	4.07	0.036	85.8	201	5.0	72
	B2	1.16	0.31	0.01	0.12	1.28	2.88	0.018	37.3	202	5.1	50
	B3	2.73	0.87	0.04	0.15	1.81	5.60	0.015	11.6	247	5.1	58
	C	3.65	3.65	0.15	0.23	1.28	10.90	0.019	3.1	392	6.0	120
D	A2	1.36	0.32	0.01	0.10	2.13	3.92	0.034	77.4	256	5.0	72
	B1	1.38	0.35	0.01	0.09	1.28	3.11	0.014	34.3	323	5.2	51
	B2	4.54	1.69	0.09	0.20	1.92	8.44	0.020	10.3	276	5.1	77
	C2	3.14	1.46	0.07	0.17	1.70	6.54	0.013	17.5	219	5.2	70
	C3	8.26	3.70	0.17	0.28	2.13	14.54	0.020	10.3	383	5.6	120
E	A1	23.15	5.45	0.07	0.59	21.30	50.56	0.809	82.1	1190	5.0	1204
	A2	1.25	0.45	0.02	0.09	3.41	5.22	0.059	13.5	120	4.5	101
	B1	0.99	0.36	0.03	0.06	3.62	5.06	0.034	8.4	142	4.7	80
	B2	1.09	0.38	0.05	0.05	2.34	3.91	0.020	4.6	190	4.9	57
	B3	2.24	0.95	0.07	0.10	2.88	6.24	0.016	5.6	232	4.8	60
G	A1	20.12	4.52	0.03	0.75	17.04	42.46	0.679	83.0	863	5.2	960
	A2	2.53	0.54	0.01	0.10	2.56	5.74	0.048	70.4	65	5.3	92
	B1	0.58	0.22	0.01	0.10	1.70	2.61	0.012	96.5	305	5.0	49
	B2	1.04	0.14	0.01	0.18	0.96	2.33	0.009	55.6	247	5.3	42
	B3	18.66	0.26	0.03	0.12	0.96	20.03	0.008	21.4	314	5.3	50
	C1	1.39	0.30	0.05	0.06	0.21	2.01	0.006	12.4	43	5.4	42
J	A1	21.72	3.92	0.07	0.15	17.04	42.90	0.531	87.1	1060	5.4	640
	A2	2.97	0.45	0.05	0.11	3.83	7.41	0.061	71.2	427	5.3	92
	B1	1.15	0.29	0.03	0.04	1.81	3.32	0.011	19.1	282	5.3	50
	B2	2.82	1.46	0.09	0.14	2.88	7.39	0.012	14.3	308	5.0	65
	C	5.35	2.99	0.16	0.21	2.24	10.95	0.014	8.2	330	5.6	83
L	A2	2.20	0.42	0.03	0.15	2.98	5.78	0.028	15.7	200	5.6	67
	B2	6.99	1.96	0.07	0.32	4.05	13.39	0.035	20.0	20	5.2	92
	C	3.40	1.42	0.06	0.14	1.49	6.51	0.015	10.3	78	5.5	63
M	A1	33.37	6.71	0.05	0.71	20.98	61.82	0.759	112.0	1240	5.7	948
	B1	1.34	0.35	0.03	0.10	2.24	4.06	0.027	48.3	203	5.1	58
	B2	2.11	0.69	0.03	0.14	1.92	4.89	0.012	14.8	345	5.1	62
	B3/C1	5.55	2.58	0.09	0.28	4.05	12.55	0.020	13.1	289	4.8	84
R3	A2	1.60	0.33	0.02	0.06	2.77	4.78	0.047	14.2	81	5.0	246
	B2	0.64	0.23	0.02	0.06	2.55	3.50	0.017	151.0	78	4.8	60
	B3	1.72	0.52	0.03	0.11	1.49	3.87	0.008	6.7	147	5.2	52
	C1	3.16	1.14	0.06	0.22	1.49	6.07	0.014	6.5	216	5.2	60
R4	A	1.36	0.25	0.02	0.06	1.70	3.39	0.016	34.4	235	5.6	70
	B	0.93	0.16	0.02	0.06	0.64	1.81	0.007	31.7	345	5.6	57
	C	2.39	0.75	0.03	0.07	0.21	3.45	0.009	23.0	84	6.9	94
Z4	A2	1.60	0.28	0.02	0.08	3.20	5.18	0.038	28.0	282	5.1	96
	B	1.16	0.32	0.03	0.07	4.37	5.95	0.028	11.7	212	4.9	72
	C	2.49	1.04	0.05	0.08	2.34	6.00	0.011	11.0	308	4.9	60

Appendix I. Throughfall data summary.

Sampling period	Plot	$PO_4^{=}$ (mg/1) $\bar{X}$	s	n	TP (mg/1) $\bar{X}$	s	n	NO_3^{-} (mg/1) $\bar{X}$	s	n	Throughfall (1) $\bar{X}$	s	n	TKN (mg/1)
8/30-9/22, '72	A	.417[a]	.259	13	--	--	--	.279[a]	.079	13	.526[a]	.110	14	--
	J	.189[a]	.101	12	--	--	--	.352[a]	.121	12	.369[b]	.098	14	--
	R3	.101	.034	9	--	--	--	.776	.230	9	.402[b]	.058	9	--
	X	.045	.013	5	--	--	--	.274[a]	.030	5	.578[a]	.032	5	--
11/5-4/7, '73	A	.083[a]	.086	7	.121[a]	.073	7	--	--	--	--	--	--	--
	J	.046[a]	.024	9	.965[a]	.025	9	--	--	--	--	--	--	--
	R3	.038[a]	.014	9	.057[a]	.018	9	--	--	--	--	--	--	--
	X	.036[a]	.009	4	.042[a]	.021	4	--	--	--	--	--	--	--
4/17-4/19, '73	A	.110[a]	.095	8	.264	.181	8	.363[ab]	.365	8	.574[a]	.224	8	1.76
	J	.023[ab]	.011	10	.050[a]	.018	10	1.114[a]	.540	10	.494[a]	.122	10	2.51
	R3	.018[b]	.013	15	.040[a]	.014	15	1.175[a]	.870	13	.476[a]	.152	15	2.45
	X	.021[ab]	.014	4	.026[a]	.017	4	.145[b]	.072	3	.959	.008	2	1.10
5/19-6/14, '73	A	.197	.078	14	.357	.137	14	.120[a]	.166	14	.820[ac]	.154	15	.43
	J	.045[ab]	.046	13	.158[a]	.070	13	.508[b]	.382	15	.683[bc]	.158	12	1.40
	R3	.086[a]	.049	15	.206[a]	.123	15	.548[b]	.261	15	.663[b]	.076	15	1.82
	X	.013[b]	.009	4	.028	.019	4	.119[a]	.078	5	.947[a]	.084	5	--
6/14-6/22, '73	A	.065[a]	.058	15	.134[a]	.112	15	.076	.062	14	.733[ab]	.170	15	.58
	J	.040[a]	.027	13	.133[a]	.047	13	.486[ab]	.252	13	.664[ab]	.103	13	1.60
	R3	.057[a]	.025	14	.129[a]	.047	14	.557[a]	.243	14	.639[b]	.085	15	1.37
	X	.015[a]	.016	4	.018	.023	4	.278[b]	.083	5	.848[a]	.101	4	3.27
6/22-7/10, '73	A	.132[a]	.085	14	.180[a]	.102	11	.273[ab]	.119	15	.842[ab]	.271	14	.46
	J	.130[a]	.095	14	.189[a]	.099	12	.347[b]	.133	14	.675[b]	.141	14	1.66
	R	.109[a]	.052	14	.139[a]	.054	14	.384[b]	.098	14	.709[b]	.072	15	1.35
	X	.004	.000	3	.015	.010	3	.189[a]	.022	5	.967[a]	.049	5	2.09

Appendix I. Continued.

Sampling period	Plot	$PO_4^{=}$ (mg/l)			TP (mg/l)			NO_3^{-} (mg/l)			Throughfall (l)			TKN (mg/l)
		$\overline{X}$	s	n	$\overline{X}$	s	n	$\overline{X}$	s	n	$\overline{X}$	s	n	
7/10-7/28, '73	A	.109^{a}	.113	6	.126^{a}	.115	6	.349^{a}	.272	6	--	--	--	.61
	J	.024^{a}	.016	5	.050^{a}	.023	4	.247^{a}	.083	5	--	--	--	--
	R	.018^{a}	.010	2	.033^{a}	.015	2	.286^{a}	.078	2	--	--	--	.53
	X	.008^{a}	.011	5	.019^{a}	.018	5	.102^{a}	.026	5	--	--	--	.33
7/28-8/31, '73	A	.258^{a}	.150	9	.329^{a}	.131	9	.326^{ab}	.211	9	--	--	--	.94
	J	.278^{a}	.208	14	.467^{a}	.383	14	.476^{a}	.226	14	--	--	--	1.36
	R3	.125^{a}	.096	12	.161^{a}	.107	12	.692^{a}	.167	12	--	--	--	.60
	X	.018	.018	3	.018	.012	3	.219^{b}	.025	4	--	--	--	.47
8/31-9/29, '73	A	.298^{a}	.230	12	.359^{a}	.265	12	.115	.094	12	--	--	--	.52
	J	.278^{a}	.299	14	.344^{a}	.328	14	.246^{a}	.082	14	--	--	--	.94
	R3	.046^{b}	.047	12	.052^{b}	.044	12	.260^{a}	.040	12	--	--	--	.90
	X	.015^{b}	.011	5	.016^{b}	.008	5	.222^{a}	.031	5	--	--	--	.50
9/29-10/20, '73	A	.989^{a}	1.208	13	1.246^{a}	.664	13	.293^{a}	.138	13	.790	.070	13	1.20
	J	.526^{a}	.459	14	0.917^{a}	.961	14	.332^{ab}	.284	14	.834^{a}	.275	14	.94
	R3	.139	.128	15	.189	.151	15	.461^{a}	.416	15	.697	.088	15	.55
	X	.009	.008	5	.015	.007	5	.169^{b}	.023	5	.980^{a}	.100	5	.27
10/20-12/8, '73	A	.087^{ab}	.097	14	.137^{ab}	.105	14	.654^{b}	.193	15	.517^{a}	.040	14	--
	J	.193^{a}	.156	15	.282^{b}	.195	15	2.543^{a}	1.478	15	.440^{a}	.100	15	--
	R3	.106^{a}	.054	15	.150^{ab}	.067	15	3.116^{a}	1.582	15	.334	.041	15	--
	X	.037^{b}	.023	4	.070^{a}	.028	4	.631^{b}	.156	4	.563^{a}	.043	4	--
5/5-5/27, '74	A	.016^{ab}	.023	12	.052^{ab}	.050	12	.310^{a}	.110	12	1.154^{a}	.226	11	--
	J	.010^{a}	.008	13	.044^{b}	.017	13	.334^{a}	.143	12	1.122^{a}	.301	11	--
	R4	.001^{b}	.001	13	.022^{a}	.008	13	--	--	--	1.084^{a}	.264	11	--
	Z	.006^{ab}	.009	12	.019^{a}	.013	12	--	--	--	1.134^{a}	.087	7	--
	X	.005^{ab}	.006	5	.026^{ab}	.016	5	.281^{a}	.017	5	1.173^{a}	.084	4	--

Appendix I. Continued.

Sampling period	Plot	$PO_4^{=}$ (mg/l) $\overline{X}$	s	n	TP (mg/l) $\overline{X}$	s	n	NO_3^- (mg/l) $\overline{X}$	s	n	Throughfall (l) $\overline{X}$	s	n	TKN (mg/l)
5/27-7/9, '74	A	.079[a]	.069	13	.117[a]	.089	13	.283[ab]	.080	13	1.404[a]	.248	12	--
	J	.074[a]	.085	15	.116[a]	.103	15	.354[a]	.119	15	1.240[a]	.218	14	--
	R4	.047[a]	.040	12	.084[a]	.055	12	--	--	--	1.507[a]	.269	10	--
	Z	.215	.120	12	.278	.148	12	--	--	--	1.177[a]	.303	8	--
	X	.017[a]	.012	3	.043[a]	.016	3	.206[b]	.022	4	1.479[a]	.077	3	--
7/9-8/12, '74	A	.315[b]	.448	14	.412[b]	.487	14	.263[a]	.210	14	1.309[ab]	.496	13	--
	J	.133[ab]	.214	15	.172[ab]	.215	15	.384[a]	.278	15	1.654[ac]	.325	13	--
	R4	.109[ab]	.153	12	.132[b]	.147	12	--	--	--	1.421[b]	.506	11	--
	Z	.207[b]	.182	15	.262[b]	.212	15	--	--	--	1.393[ab]	.400	15	--
	X	.009[a]	.008	4	.031[a]	.017	4	.237[a]	.051	5	1.749[c]	.062	5	--
8/12-9/13, '74	A	.249[a]	.233	14	.406[a]	.389	14	.261[a]	.177	14	.694[b]	.258	14	--
	J	.268[a]	.234	15	.245[a]	.224	15	.482[a]	.381	15	.971[ab]	.400	15	--
	R4	.336[a]	.428	12	.373[a]	.436	12	--	--	--	.863[ab]	.191	12	--
	Z	.488[a]	.509	15	.420[a]	.360	14	--	--	--	.780[b]	.158	14	--
	X	.019	.013	4	.027	.017	4	.229[a]	.038	5	.975[a]	.058	5	--
9/13-11/6, '74	A	1.089[a]	.884	14	1.365[a]	1.027	14	.171[a]	.118	14	1.533[b]	.145	11	--
	J	.269[b]	.172	14	.290[b]	.205	14	.316[a]	.389	15	1.477[bc]	.128	14	--
	R4	.709[ab]	.899	15	.722[ab]	.874	15	--	--	--	1.309[ac]	.175	14	--
	Z	1.414[a]	.743	13	1.486[a]	.789	13	--	--	--	1.324[a]	.108	12	--
	X	.001	0	2	.017	.013	2	.228[a]	.158	2	1.599[b]	.068	4	

Note: Values within a vertical column for a given sampling date that are followed by the same letter are not significantly different ($p<.05$).

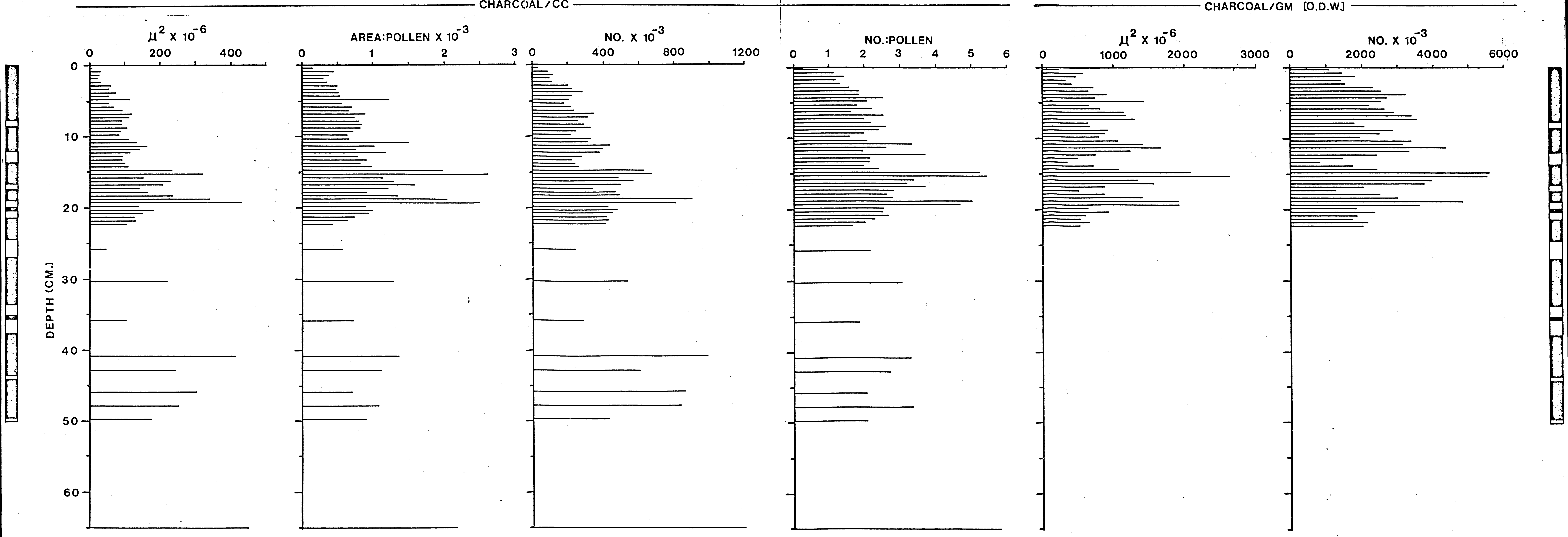


Figure 12. Charcoal profiles for Squaw Lake.

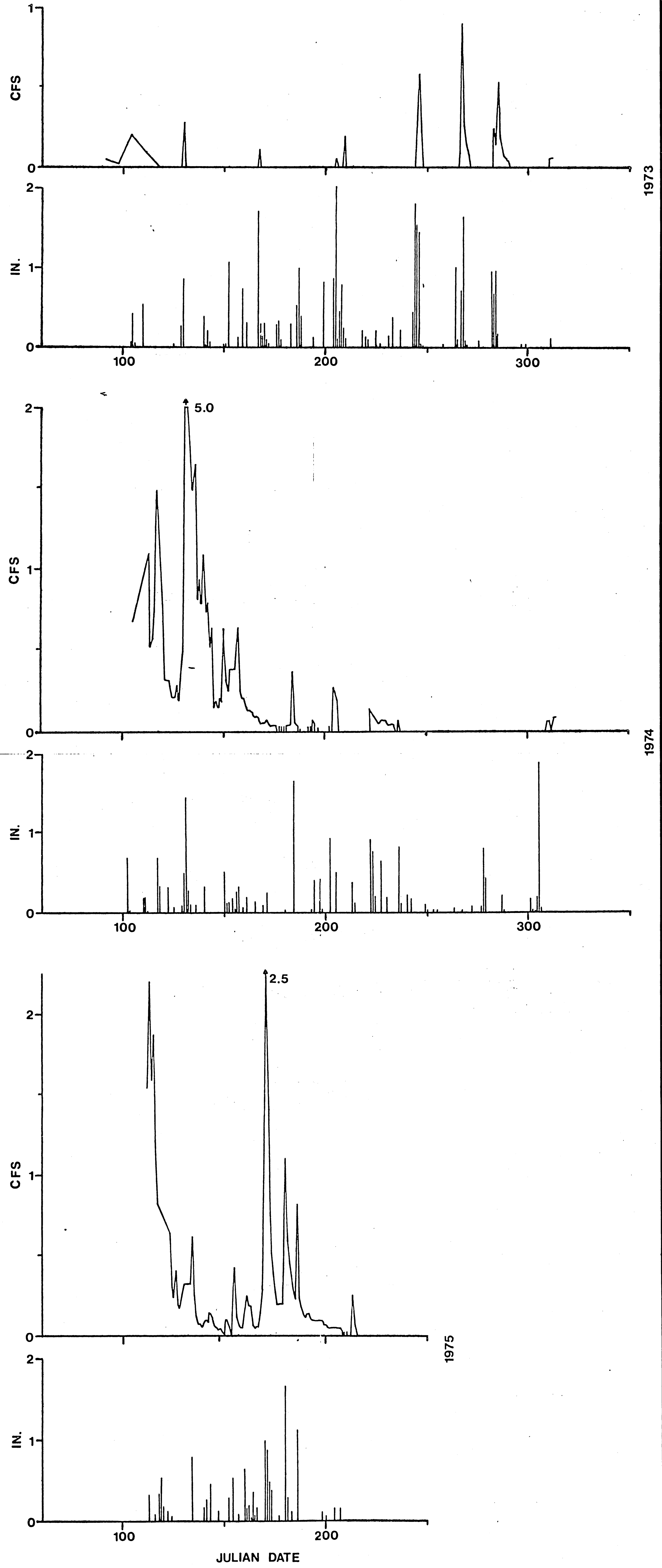


Figure 14. Precipitation and PST1 discharge data for 1973-1975.

Figure 9. Pollen diagram for Squaw Lake.

Figure 11. Pollen diagram for Myrtle Lake.